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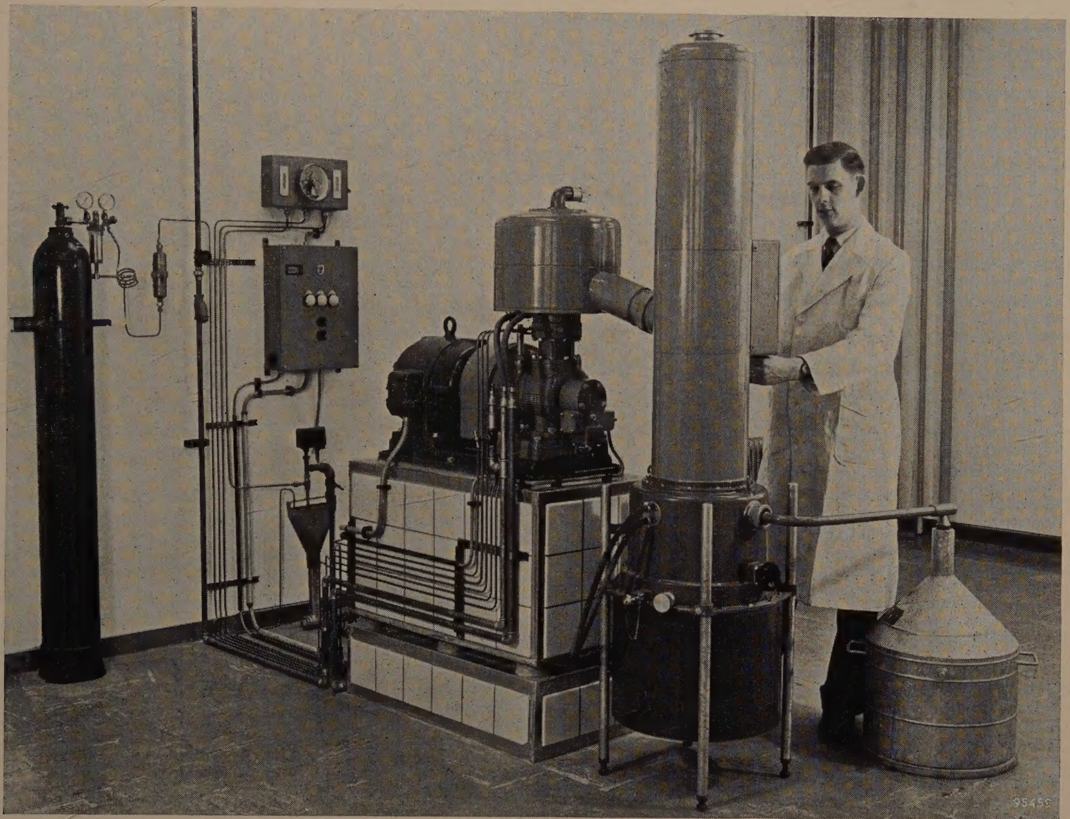

A SMALL AIR FRACTIONATING COLUMN USED WITH A GAS REFRIGERATING MACHINE FOR PRODUCING LIQUID NITROGEN

by J. van der STER and J. W. L. KÖHLER. 621.573.049.2:546.17-14

The advent of the gas refrigerating machine has made it possible to build a simple and economically working installation for producing pure liquid nitrogen from atmospheric air. The article below describes the operation and construction of such an installation which has been developed in the Philips laboratories, Eindhoven, and is now on the market.

Recent years have seen a marked increase in the use of liquid air and liquid nitrogen in laboratories and in industry. These extremely cold liquids, whose respective temperatures are about —194 °C and —196 °C, are used primarily for purposes of cooling. They find application, for example, in vacuum technique (absorption of residual gases at low temperature), in research on the properties of solids at low temperatures, for the shrink-fitting of precision components and for the "freezing-in" of a state of chemical equilibrium.

Moderate amounts of liquid air can be made simply and cheaply with the gas refrigerating machine 1). When working with liquid air, however, certain precautions are necessary, for it can be dangerous if brought into contact with inflammable substances. For this reason, and also when the temperature of a cooling bath is to be kept very constant, it is often preferable to use liquid nitrogen. Liquid nitrogen can, of course, be produced by condensing nitrogen from a cylinder with the aid of a gas refrigerating machine, but this calls for a regular and considerable supply of cylinders if continuous production is required.

The installation which is the subject of this article produces liquid nitrogen from atmospheric air. The installation, which is fully automatic, consists essentially of a gas refrigerating machine and a fractionating column, and delivers 4 to 5 litres of liquid nitrogen per hour. It differs from other air-fractionating plants in that it does not involve compression of the air. In consequence the installation is light and simple in design and moreover small.

Before describing the installation, we shall deal briefly with the physical principles of the separation of gases and consider the construction and operation of a fractionating column.

Separation of the components of the gas mixtures

Physical principles

If we determine, at constant pressure, the boiling point of some mixtures of, say, liquid oxygen and nitrogen, and the dew point of some vapour mixtures (i.e. the temperature at which condensation occurs upon cooling), we find that the boiling point of a given liquid mixture does not coincide with the dew point of a vapour mixture of the same composition; the dew point is always higher than the boiling point. In a phase diagram, showing temperature versus composition (T, x diagram, *fig. 1*), the dew points corresponding to the various compositions together form the *vapour curve V* and the boiling points the *liquid curve L*. At the extreme left and extreme right of the diagram, where the concentration of one of the components is 100%, the two curves meet at a point, the ordinate of which gives the boiling point of this compound.

It can be seen from the diagram that when a liquid and a vapour are in equilibrium, i.e. when they have the same pressure and temperature, the vapour in our example contains more nitrogen than the liquid (denoted in fig. 1, e.g. by points D and C). On the other hand, when a boiling liquid and a saturated vapour of the same composition are brought together (points B and A, respectively) the liquid, as already mentioned, is colder than the vapour. The vapour, then, will tend to condense on the surface of the liquid. The oxygen will show the greater tendency to do so, since pure oxygen condenses at a temperature 13 °C higher than pure nitrogen. The result is that, when equilibrium is reached, the vapour has become richer in nitrogen and the liquid richer in oxygen. The final state arrived at, for example either C and D or C' and D', depends on the relative proportions of liquid and vapour originally brought together. Similarly, a state of equilibrium, say C-D, can be reached starting from vapour and liquid mixtures of unequal composition, denoted for example by E and F.

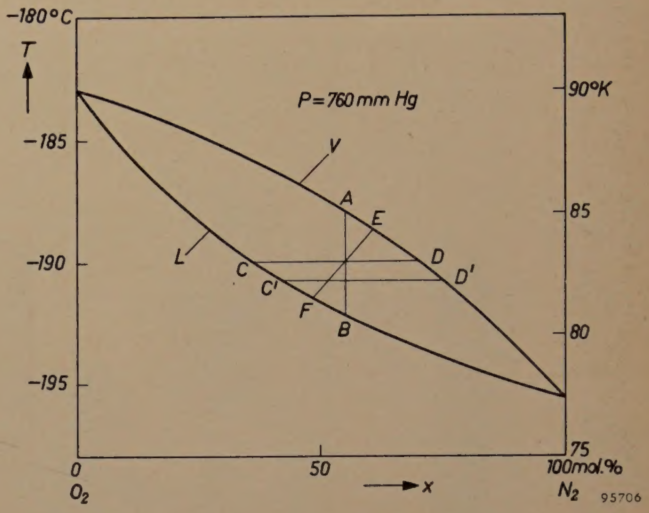

Fig. 1. Phase diagram for mixtures of oxygen and nitrogen under a pressure of 1 atm. The percentage of nitrogen is set out along the abscissa (x) and the temperature (T) on the ordinate. The curve V indicates the variation of the dew point, curve L the variation of the boiling point. The dew point of a vapour of a given composition is always higher than the boiling point of a liquid with the same composition. Starting from a quantity of boiling liquid and a quantity of *warmer* (saturated) vapour, a state of equilibrium is always reached (liquid and vapour temperatures equal) whereby the vapour is enriched in nitrogen and the liquid in oxygen.

Accordingly, when the system changes to a state of equilibrium from a non-equilibrium state in which the vapour is warmer than the liquid, the vapour always becomes richer in nitrogen and the liquid richer in oxygen. This phenomenon can be utilized for separating a mixture into its components. In practice a fractionating column is used for this purpose.

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1) For a description of the principles and construction of the gas refrigerating machine, see J. W. L. Köhler and C. O. Jonkers, Philips tech. Rev. 16, 69-78 and 105-115, 1954/55.

Construction and operation of a fractionating column

A fractionating (or "rectifying") column is essentially a vertical tube containing a number of horizontal baffle plates and in which a certain temperature gradient is maintained (cold above and warm below). A stream of liquid flows from top to bottom and a vapour stream from bottom to top.

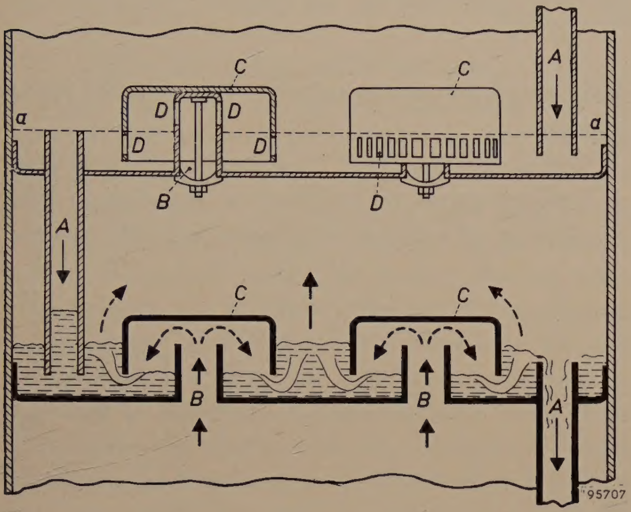

Fig. 2. Schematic representation of part of an air fractionating column, showing two baffle plates. The sketch of the upper plate gives an idea of the geometry and construction of one of the many possible forms; the lower sketch illustrates the passage of vapour and liquid through the plate. *A* overflow pipes, *B* vapour inlet, *C* bubble cap, *D* openings through which vapour passes, *a-a* level of liquid if no vapour should pass through.

Both streams pass the plates, which are designed to establish intimate contact between liquid and vapour. When they leave a plate, liquid and vapour are accordingly in equilibrium, whether or not they were so before arriving at the plate (*fig. 2*).

Fig. 3a represents schematically part of such a fractionating column. The dashed lines p, q and r are three plates. The arrows indicate the flow of liquid and vapour to and from the plates. Fig. 3*b* shows a phase diagram in which the points denoted by letters represent the composition and temperature of the liquid or vapour mixtures denoted by the same letters in fig. 3*a*. Since a temperature gradient prevails in the column, the liquid (E) flowing down to the plate q has a somewhat lower temperature than the vapour (N) that reaches this plate from below. Upon leaving the plate they are in equilibrium, i.e. in fig. 3*b* the points E and N have moved to F and O, respectively. The vapour continues upwards to plate p, where it is again enriched in the more volatile component (point P), while the liquid is enriched at plate r in the less volatile component (point G). Thus, as the vapour rises, the point on the vapour line in fig. 3*b* shifts increasingly towards the right. Finally it reaches approximately the point K_N, which means that at the top of the column the vapour consists almost entirely of the more volatile component.

The vapour mixture to be fractionated enters the column about half-way up, having been cooled beforehand to approximately the temperature prevailing at that position. It then undergoes the process described, whereby its components are separated. The more volatile component leaves the column at the top (the top product) and the other component (the bottom product) leaves at the base.

In small columns a filling of an appropriate packing material is often used instead of baffle plates. Like the plates, the packing is required to establish intimate contact between vapour and liquid; in other words, vapour and liquid must remain uniformly distributed over the surface of the packing, which should be large per unit volume. If large columns are filled with such packing, there is a tendency for the liquid to stream down one side, which adversely affect the column's efficiency. To avoid the latter phenomenon ,and for various other reasons, large columns are almost invariably equipped with plates.

In order to maintain the flow of liquid, part of the top product is condensed and returned to the column as "reflux". For the column to function properly, the ratio between the reflux and the fraction of the top product taken off must exceed a certain minimum value. We shall return to this subject presently. Similar considerations apply to the bottom product: part is tapped off and part ascends again as vapour.

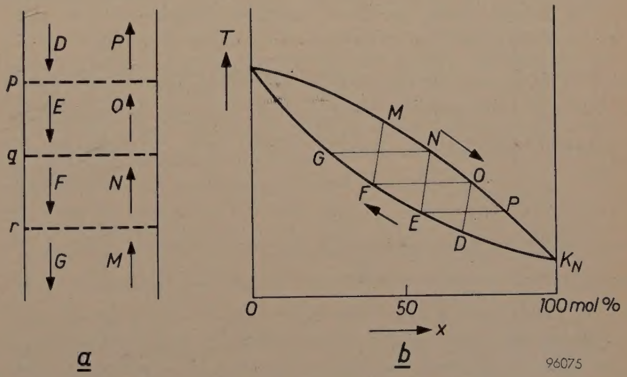

Fig. 3. Separation of a gas mixture. *a*) Schematic diagram of part of a fractionating column containing three plates (p, q and r). When a temperature gradient exists in the column (cold above, warm below), the descending liquid and the ascending vapour undergo a change in composition every time they pass a plate.
b) Phase diagram. The points denoted by capital letters represent the properties (T, x) of the vapour or liquid at the positions denoted by the same letters in fig. 3*a*. The liquid becomes increasingly richer in the less volatile component, and the vapour increasingly richer in the other (x = 100%).

For the condensation of the top product it is clearly necessary to absorb the heat dissipated, while to evaporate the bottom product heat must be supplied. Given the mixture to be fractionated, i.e. given the temperatures prevailing at the top and bottom of the column, it is the designer's task to ensure that dissipation and supply of heat take place in the most economical manner. If the column temperature is above room temperature, as it is in the fractional distillation of crude oils, the cooling can usually be effected with mains water and the heating with steam. The problem is then simple. In the fractionation of air, which takes place at about —190 °C (the temperature must be —183 °C at the bottom of the column and —196 °C at the top) the way in which the requisite refrigeration and heat transfer are achieved governs the efficiency and simplicity of the installation.

The physics of this heat engineering problem may be further examined with the help of *fig. 4*. The figure represents schematically a fractionating column *K*, with a condenser *T* at the top, which produces the reflux, and a boiler *B* at the bottom, in which a part of the bottom product is vaporized to maintain the ascending vapour stream. The temperatures of condenser and boiler are respectively T_T and T_B, where $T_T < T_B$. The mixture enters the column at *M*, and its components, P_T and P_B, leave the column at *T* and *B*, respectively. To condense the reflux, it is necessary in the stationary state for a heat flow Q_T to leave the condenser, and in order to vaporize part of the bottom product a heat flow Q_B must be supplied to the boiler.

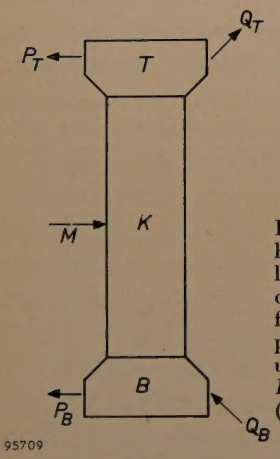

Fig. 4. Supply and withdrawal of heat in an air fractionating installation. *K* column, *B* reboiler, *T* condenser. The mixture to be fractionated enters at *M*. P_T top product (mol/sec), P_B bottom product (mol/sec), Q_B heat supplied to *B* (J/sec), Q_T heat withdrawn at *T* (J/sec).

If the air entering the column and P_T and P_B leaving it are all in the saturated gaseous state, then to a first approximation $Q_T = Q_B$. Thus, the fractionation of a gas mixture requires the existence of a heat flow only in the column itself, i.e. in that part of the installation shown in fig. 4. To maintain this heat flow, external plant is needed for conveying per second an amount of heat Q_T ($\approx Q_B$) from *T* to *B*, that is from a colder to a warmer point. Energy must of course be supplied to the plant for the purpose (second law of thermodynamics).

If the top product is to be tapped off in liquid form, the absorbtion of heat Q_T must be increased by the latent heat of condensation of the top product. Similarly, if the bottom product is to be tapped off in liquid form, the latent heat of condensation of P_B must be subtracted from the heat Q_B fed to *B*.

In air fractionating installations, ingenious but intricate methods of vapour condensation and liquid evaporation have hitherto been employed for supplying heat to *B* and withdrawing heat from *T*. The medium is the air itself or one of its fractionated components, and therefore the air must be compressed [2]).

Principle of the new installation for producing liquid nitrogen

With reference to *fig. 5* we shall now discuss the underlying principle of the new installation, the application of which first became possible with the advent of the gas refrigerating machine. Element *A* in the figure is the gas refrigeration machine, element *B* the fractionating column and element *C* a heat exchanger, which also serves as a water and CO_2 trap. Air (*1*) is fed into the system and liquid nitrogen (*2*) and gaseous (impure) oxygen (*3*) are extracted. The air feed is pre-cooled in the heat exchanger *C* by the oxygen exhausted from the column; it is also partly dried in *C*. By heat exchange with the liquid oxygen at the base of the column the air is further cooled and at the same time the residual water vapour and carbon dioxide are removed. The air then enters the fractionating column at a suitable point between top and bottom.

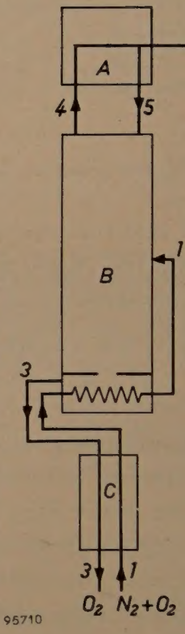

Fig. 5. Block-diagram of liquid-nitrogen installation. *A* gas refrigerating machine, *B* fractionating column, *C* heat exchanger (also water and CO_2 trap). The oxygen evaporating at the bottom of *B* (the reboiler) leaves the installation via *C* (*3*), where it cools the incoming air (*1*) and thereby attains room temperature itself. The air is further cooled in the reboiler and enters the column part way up. Saturated nitrogen vapour (*4*) leaves the column at the top and is condensed by the refrigerating machine. Part of the condensate is tapped off (*2*) and part is returned to the column as reflux (*5*).

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[2]) This subject is treated at length in Handbuch der Kältetechnik, Part 8, Springer, Berlin 1957, and in M. Ruhemann, The separation of gases, Oxford University Press, 1949. See also: H. C. A. Holleman, Philips tech. Rev. 4, 128-135, 1939.

The virtually pure nitrogen vapour leaving the column (*4*) is condensed by the gas refrigerating machine. Part of this condensate is returned to the column as reflux (*5*) and the remainder is taken off as product (*2*). Cooling of the air at the base of the column (termed the "reboiler") causes the evaporation of liquid oxygen. Part of this vapour is returned to the column, and the remainder is blown out via *C*.

It will be noted that, whilst the column delivers nitrogen vapour at the top and liquid oxygen at the bottom, the products extracted from the installation are *liquid* nitrogen — the required product — and oxygen *gas*. If the liquid oxygen were to be tapped off at the base, it would not be possible to utilize its stored "cold" for cooling the air feed. The consequence would be a drop in the production of liquid nitrogen. This is at once apparent when it is remembered that the machine's refrigerating capacity is constant, and also that the "cold" now leaves the installation only in the form of liquid products. The extraction of liquid oxygen is thus not impossible. However, the production of liquid oxygen is only about a quarter of the liquid nitrogen production; it is unlikely that this production ratio will be just that required by the user.

In the next section we shall examine the way in which the reflux ratio is affected by the design of the system described above.

Before the installation can function it must first be cooled to the working temperature which, as we have seen, is between —196 °C and —183 °C. For this purpose, air is fed directly to the gas refrigerating machine via another water and CO_2 trap [3]). The liquid air so produced flows to the column and cools its interior by evaporation.

Reflux ratio; theoretical considerations

We shall first calculate the minimum reflux necessary for a gas fractionating column to function properly. We base the calculation on the equilibrium mass transfer in the part of the column lying between the inlet point and the top.

This part of a column is represented by the diagram in *fig. 6*. The arrows indicate the liquid and vapour flows, the dashed lines the plates immediately above and below the inlet. The letters between brackets represent the concentration of the lighter — i.e. the more volatile — component. The mixed feed (air) enters the column, in the form of a saturated vapour, at the rate of F mol per second. We let z_F denote the concentration of the lighter component in the feed (in our case the nitrogen content). Of the condensed top product (concentration z_T), T mol per second is tapped off and L mol per second returned to the column. For the sake of simplicity we assume that there is no heat transfer between the column itself and the surrounding medium, and further that the latent heat of evaporation is the same for both components. In this case the descending flow of liquid is uniform though not, of course, constant in composition, over the whole height of the column. Counter to this flow of liquid there is a vapour stream of (V—F) mol per sec below the inlet and V mol per sec above.

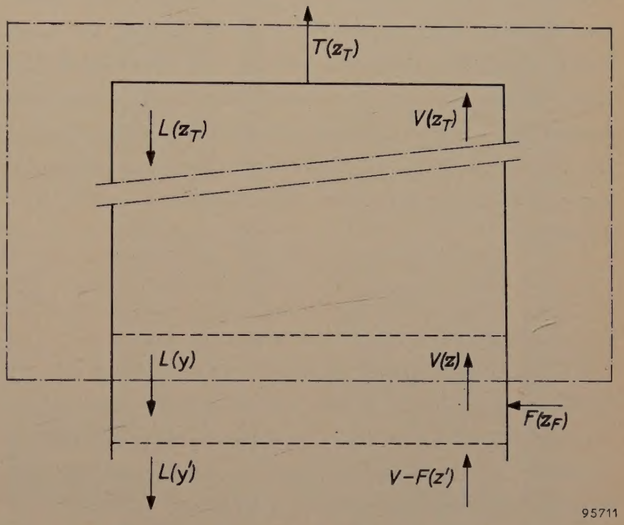

Fig. 6. Mass balance of part of a column situated between the inlet and the top, assuming that both components have the same latent heat of evaporation. The rates of vapour and liquid flow are accordingly constant over the whole height of the column (V and L mol/s). The mixture to be fractionated enters at the rate of F mol per second; the vapour flow below the inlet is V—F. The flow of the extracted top product is T. The dashed lines represent the baffle plates immediately above and below the inlet. The concentration of the volatile component, which changes from plate to plate, is indicated between brackets.

In the stationary state there can be no accumulation of either of the components, that is to say as much of each component enters the outlines part in fig. 6 as leaves it. For the more volatile component this yields the relation: $T \times z_T = V \times z - L \times y$, and for both components together: $T = V - L$. From these relations we can calculate the reflux ratio r, which is of course equal to L/T. We find:

$$r = \frac{z_T - z}{z - y} . \qquad \dots \dots \dots \quad (1)$$

In the state of equilibrium the vapour issuing from the plate just under the inlet has acquired the same concentration as the mixture entering the column. Hence z is equal to z_F, and the formula for the reflux ratio becomes:

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[3]) In the starting period the air cannot follow the normal path via the heat exchanger and the reboiler. At this stage these elements are not yet cooled and therefore trap no water or carbon dioxide, so that stoppages might be caused elsewhere in the installation.

$$r = \frac{z_T - z_F}{z_F - y} \quad \ldots\ldots\ldots \quad (2)$$

A similar consideration tells us more about the value of y and leads to the minimum condition for r. In a working column the vapour when ascending must become increasingly richer, and the liquid when descending increasingly poorer, in the lighter component; in other words, y must be greater than y' (see fig. 6). But the concentration y' applies to the liquid issuing from the plate immediately below the inlet, and this liquid is in equilibrium with the vapour of concentration z_F. The value of y', then, is a fixed quantity and for a given z_F can be read from the phase diagram (cf. fig. 1). We shall call this value y_{z_F}. The column can only function properly, i.e. deliver a top product of concentration z_T, provided that y is greater than y_{z_F}, that is provided r is greater than the value r_0 given by the equation:

$$r_0 = \frac{z_T - z_F}{z_F - y_{z_F}} \quad \ldots\ldots\ldots \quad (3)$$

For producing pure nitrogen ($z_T = 1.00$) by air fractionation ($z_F = 0.78$), the value of r_0 according to equation (3) is 0.7. Exact calculation, taking account of the exact values of the molar latent heat of evaporation, yields a value of 0.8 for r_0 [4]). This means that, in order to extract one mol of nitrogen, at least 0.8 mol of liquid N_2 must be returned to the column as reflux. Thus, for every litre of liquid extracted, at least 1.8 litres must be condensed.

The appropriate value of r in a given case, that is to say, the amount by which r must exceed r_0, depends on the length of the column (the condition $r > r_0$ having been derived from the condition $y > y'$). If r approaches r_0, then y approaches y', which means that the gain in concentration per baffle approaches zero. Where $r = r_0$, the fractionation would therefore require an infinite number of plaves. In practice, excess reflux is always employed in order to keep the size of the column within reasonable limits.

The reflux ratio in the new installation

With an installation operating on the principle illustrated in fig. 5, the value of r cannot be freely chosen; on the contrary, r is a fixed quantity. In order to examine the factors that here govern the reflux ratio in the new installation and to ascertain the value of r, we shall draw up a heat balance, on the basis of the block diagram in *fig. 7*. The elements A, B and C represent, as in fig. 5, the gas refrigerating machine, the column and the heat exchanger, respectively.

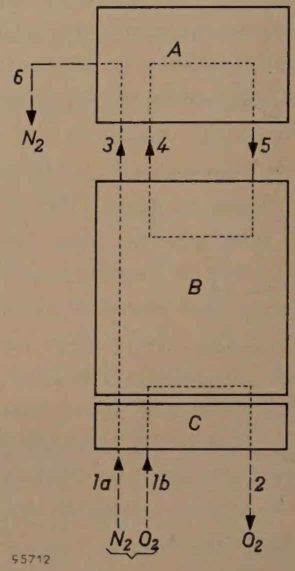

Fig. 7. Heat balance of the installation. A gas refrigerating machine, B column, C heat exchanger, *1* inflowing air (*1a* nitrogen, *1b* oxygen), *2* expelled oxygen; flows *1b* and *2* compensate each other thermally. Flow *1a* is of the same magnitude as flows *3*, = *6*, which represent the tapped-off fraction of the top product; this flow supplies 6190 joules per mol. Flow *4* is the fraction of the top product used as reflux after condensation. Flows *4* and *5* can be regarded as a circulating quantity of nitrogen of constant temperature, which withdraws from the column 5600 joules per mol (the latent heat of evaporation of nitrogen).

Air at room temperature (*1a* and *1b*) enters the installation, oxygen of the same temperature (*2*) and liquid (boiling) nitrogen (*6*) leave it. The ingoing and outgoing amounts of oxygen are equal; the same is true of the nitrogen. The oxygen from the air going in (*1b*) and the oxygen exhausted (*2*) thermally cancel out and may therefore be disregarded for the purposes of the heat balance. The nitrogen that will ultimately leave the installation as product is initially at room temperature, but leaves the column as saturated vapour at —196 °C (*3*). This cooling involves the dissipation of 6390 joules per mol. Finally, we consider the fraction of the top product that is not tapped off (*4*) and the reflux (*5*). The streams (*4*) and (*5*) together form a closed circuit in which nitrogen, possessing the purity of the top product, circulates. During a complete circulation this nitrogen does not change in temperature. It is, however, continuously condensed in A and again evaporated in B. As a result, 5600 joules per mol reflux are withdrawn from B. Since 1 mol extracted product corresponds to r mol reflux, this means that 5600 r joules are taken from the column per mol product. In the state of thermal equilibrium this energy is exactly equal to the above 6390 joules, and therefore the value of the reflux ratio r is 1.14.

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[4]) W. H. Keesom, Rapports et Communications No. 17, 6e Congrès International du Froid, Buenos Aires 1932, p. 136; or, Comm. Kamerlingh Onnes Lab. Univ. Leiden **19**, 1929/31, Suppl. No. 69. Further ibid. **20**, 1931/33, Suppl. No. 72a, and W. H. Keesom and W. Tuyn, ibid. **20**, 1931/33, Suppl. No. 72b.

This value is appreciably higher than the minimum reflux ratio r_0, which, as we have seen, is about 0.8.

The foregoing considerations show that with an air fractionating installation operating on the principle described in fig. 5 the equilibrium value of r is fully determined by the thermal properties of the top product, which in our case is nitrogen. As will be recalled, the value of r_0 is governed not only by the requisite purity of the top product but also by the composition of the mixture to be fractionated and by the shape of the phase diagram. It may very well be that for some gas mixtures the equilibrium value of r is smaller than r_0. The system described — which has proved eminently suitable for an air fractionating installation required to deliver liquid nitrogen — is thus not universally applicable. For instance, an analogous system cannot be used for producing pure liquid oxygen from air.

Regulation of the column

It is most important that a small installation like the one under discussion should be simple to operate. The only deliberate control operations in the present case are limited to starting up the installation; thereafter the control is fully automatic. Regulation is necessary for the flow of the air feed, the flow of the oxygen waste product, and also the division of the condensate (the liquid nitrogen) into reflux and extracted product.

The flow of the air feed is maintained by the sub-atmospheric pressure produced in the installation owing to the condensation of the saturated nitrogen vapour, measures having been taken (see below) to make it impossible for the air to enter the column except via the entry port. The air is therefore sucked into the column in the right amount, without the need for a regulating device. Regulating devices are, however, necessary in the other cases and these will now be discussed with reference to *fig. 8*. This figure shows in diagrammatic form the column (*1*), the reboiler (*2*) and the various means of regulation; for the sake of clarity, most other components of the installation are omitted.

Removal of oxygen

Since a certain negative pressure prevails in the column, the oxygen cannot simply be blown out if the column and reboiler are in direct communication. In order nevertheless to allow this straightforward method of removal to be adopted, the installation is in the first place so designed that the liquid from the column can only enter the reboiler through the standpipe (*3*). In the second place the fraction of the vaporized oxygen flowing back to the column can only enter the column through pipe (*4*) which contains an adjustable flow resistance in the form of a valve (of comparatively wide through-way, however). The latter is adjusted in such a way that the pressure drop across it causes the pressure in the reboiler to rise above that of the atmosphere. The oxygen is then automatically blown out.

The gauge pressure in the reboiler is proportional to the amount of oxygen that evaporates, and this

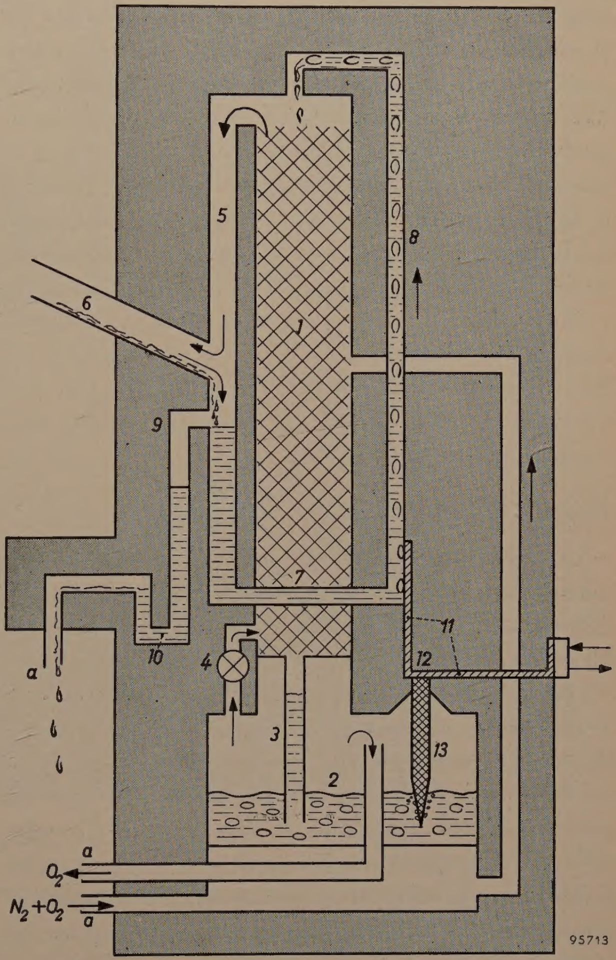

Fig. 8. Regulation of the column. The liquid from the column *1* can only reach the reboiler *2* via the standpipe *3*. The evaporating oxygen in *2* returns partly to the column via the valve *4*. This is so adjusted that the pressure in *2* is slightly higher than atmospheric pressure, so that oxygen vapour is blown off. The saturated nitrogen vapour leaving the column at the top enters the refrigerating machine via tubes *5* and *6*; after having been condensed, it flows back through *6* into the lower part of tube *5*. The latter forms the high-density arm of a vapour-bubble pump (*5*, *7*, *8*), which pumps the reflux to the top; tube *8* is heated by means of a copper strip *11* to which a finger *13* is fixed. The tip of the finger reaches into the liquid in the reboiler. If the reflux is excessive, the level in *2* rises, and the pin withdraws more heat from strip *11*, thereby slowing down the pumping action. The product is extracted via the overflow *9* and the trap *10*.

is roughly proportional to the amount of air sucked in, for it is this air that supplies the heat needed to evaporate the liquid in the reboiler. A variation in the quantity of incoming air therefore automatically gives rise to an approximately equal (relative) change in the quantity of oxygen exhausted; in other words, the ratio between these two quantities remains nearly constant. Since air contains 78% nitrogen, at least 22% of the gas mixture sucked in must be exhausted [5]). The valve is so adjusted that 25 to 32% is exhausted, which means that the vapour so removed consists partly of nitrogen. Thus, for a given production of liquid nitrogen, more air is sucked in than would be the case if exactly 22% were exhausted. It might be thought that this would entail some loss of energy and adversely affect the efficiency of the installation. This is not so, however, the reasons being that the air is not compressed (hence there is no loss due to the work of compression) and that the waste product is again raised to room temperature. Accordingly, fairly coarse adjustment of the valve is permissible, which simplifies operation.

The solution described has proved entirely satisfactory, even in the face of *wide* variations in the capacity of the refrigerating machine, in the humidity of the air and in the accumulation of deposits in the heat exchanger.

Division of liquid nitrogen into product and reflux

In reality the refrigerating machine is not above the column, as might be suggested by fig. 5, but at the side of it, and therefore the reflux has to be pumped up to the top of the column. This is done by means of a *vapour-bubble pump,* which is essentially merely a U-shaped tube partly filled with liquid. In one limb of the pump — the "riser" tube — the liquid is "diluted" with vapour bubbles. The specific gravity of the contents of this tube is thereby reduced, causing the liquid level to rise. The vapour bubbles are produced by evaporating the liquid to be pumped. For this purpose heat is applied to the base of the riser tube [6]).

In fig. 8 the pump is composed of tubes *5*, *7* and *8*. The riser tube is heated by means of a copper strip *11*, one end of which is fixed to tube *8* near the bottom, while mains water flows over the other end. The system functions as follows. The vapour leaving the top of the column flows to the gas refrigerating machine through the upper part of tube *5* and through tube *6*. The condensate runs back down tube *6* and passes into the lower part of tube *5*. The level of the liquid in the latter tube is in principle determined by the height of tube *8*, and by the concentration of bubbles in the liquid in this tube. At a given bubble concentration this level exactly coincides with the overflow outlet *9*. If the bubble concentration is greater, this level is not reached and all liquid nitrogen emanating from *6* is returned to the column as reflux. If the bubble concentration is less, part of the condensate leaves the installation via *9* and the trap *10*.

The use of a vapour-bubble pump makes it possible to divide the condensate into product and reflux simply and automatically by the expedient of regulating the heat supply. The heating strip *11* is so designed as to conduct slightly too much heat to the riser tube. Fixed to this strip at point *12* is a copper "finger" *13* which passes through the cover of the reboiler into the liquid oxygen. The position of point *12* is so chosen that its temperature is higher than that of the liquid oxygen when the liquid level in the reboiler is below the tip of the finger. If the reflux is excessive the level in the reboiler rises. As a result the temperature of point *12* drops and less heat is conducted to the pump. The latter then pumps up less liquid, and the reflux accordingly decreases until equilibrium is reached. The shape of the finger is such that the system cannot go into oscillation. Good thermal insulation is, of course, provided between the finger and the cover of the reboiler.

Another great advantage of using a vapour-bubble pump and the system of regulation just described is that no moving parts are involved.

Starting-up the installation

During the starting period, the gas refrigerating machine sucks in ambient air directly, as already mentioned. The openings marked *a* in fig. 8 are then closed. The liquefied air flows via tube *6* to the column, where it evaporates. Air then flows back through *6* to the condenser of the machine, where it is again liquefied, passes again to the column, and so on. This means that only a very limited amount of air (about 1 m^3) need be sucked in from outside for cooling the installation, thus allowing the water and CO_2 trap on the refrigerating machine to be kept small in size.

After some time the liquid in the reboiler rises to a level high enough to bring pin *13* into play, whereupon the vapour-bubble pump forces less liquid up the tube. The level of liquid in tube *5*, which can be read from a meter, then rises also. One can now switch over to the normal situation. The final step is to adjust the valve *4* to the appropriate setting, by consulting the meters that indicate the quantities of air and oxygen respectively sucked in and blown out per second. The starting period lasts altogether about $1^1/_2$ hours.

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[5]) This 22% is composed of 21% oxygen and 1% argon. Since there is little difference between the thermal properties of these gases, the argon behaves in this installation in the same way as the oxygen.

[6]) The bubble pump widely used in the oil industry is based on the same principle, but in this case the "dilution" is effected with a gas which is forced through a nozzle or a porous plug into the liquid.

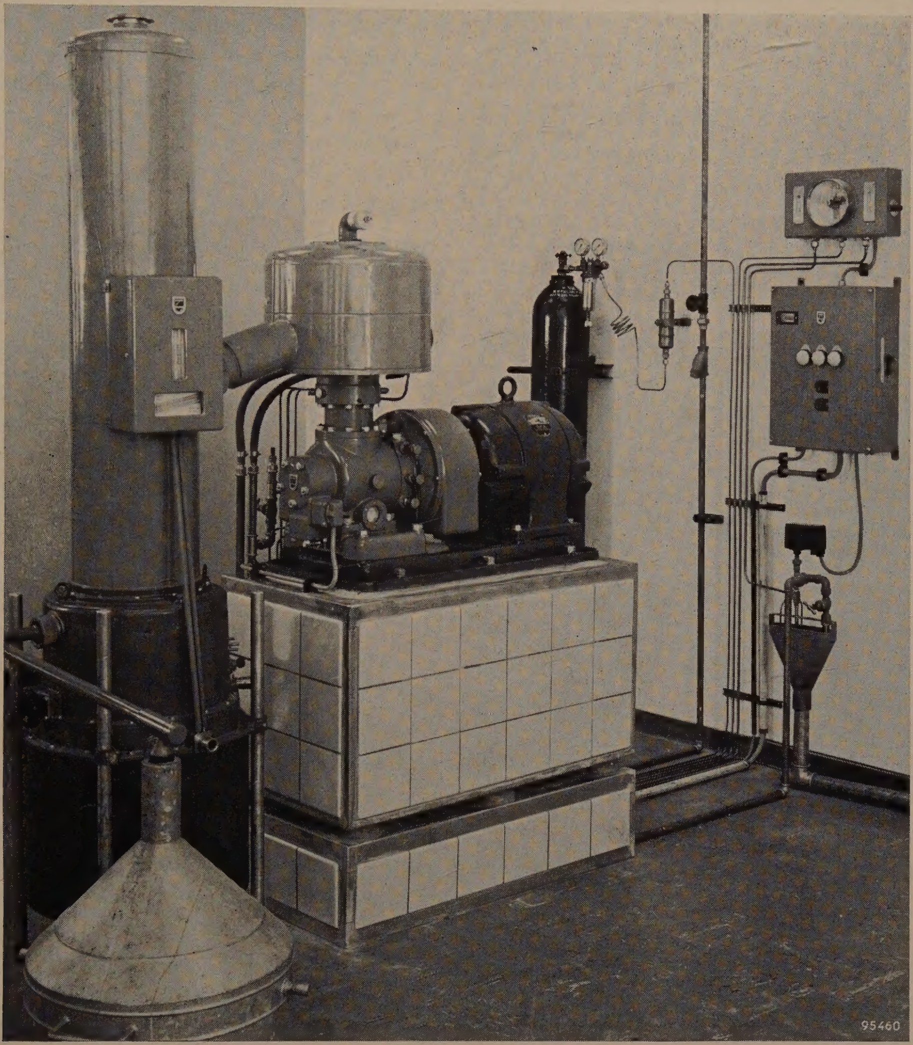

Fig. 9. The Philips liquid-nitrogen installation type PW 7050. Left, the air fractionating column which forms a single unit with the water and CO_2 trap mounted at the base. Centre, the gas refrigerating machine, on which is mounted (under the same hood) the condenser and a second water and CO_2 trap; the latter functions during the starting period. The instrument panel mounted on the column jacket contains meters for reading the flow of incoming air, the flow of expelled oxygen and the level of liquid in the high-density arm of the reflux pump. The installation delivers 4 to 5 litres of liquid nitrogen per hour with a power consumption of 6 kW and can operate continuously for a week. The entire installation covers a floor area of only 0.50 × 2.00 m.

Technical details and performance

As we have seen, the actual lay-out of the installation differs from that shown diagrammatically in fig. 5 in that the refrigerating machine is mounted at the side of the column instead of on top of it (see *fig. 9* and title photograph).

This layout has the virtue of making all components of the installation readily accessible and it also allows easy decoupling of column and refrigerating machine. A convenient feature of this construction is that, by removing the column from the refrigerating machine and fitting the latter with another condenser, one has a simple installation for producing liquid air. Similarly, by reversing the procedure, one can easily convert a liquid air installation into an installation for producing liquid nitrogen from atmospheric air.

When the installation is working, the temperature of the column is extremely low, and since heat losses must be avoided as far as possible, the actual column is sheathed in a thick layer of insulating material. What can be seen in fig. 8 is only the jacket around this insulation. The insulating material used is silica-aerogel, a powdered substance with especially favourable properties in that it has very low thermal conductance and can be poured, making it a simple matter to fill up the space reserved for insulation.

The actual column is a tube, 4.5 cm in diameter and 90 cm in length, which is filled to the top with a packing material. The packing consists of small pieces of wire gauze bent into a saddle shape (see *fig. 10*). At the top, and at the air inlet, distributors ensure uniform distribution of the liquid.

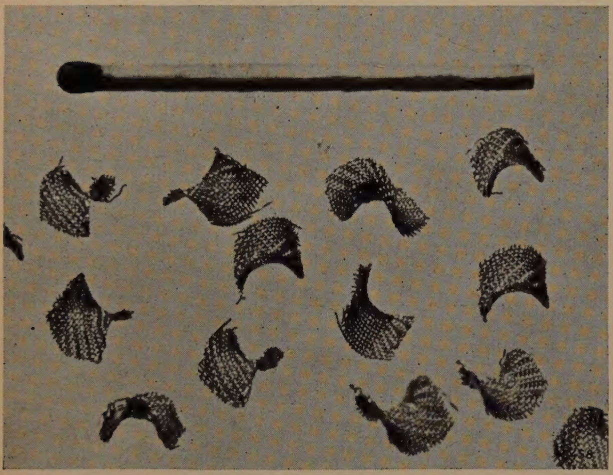

Fig. 10. The saddle-shaped pieces of metal gauze forming the packing in the fractionating column.

We shall not deal with the constructional details of the heat exchanger, in which the expelled oxygen cools the indrawn air, and which also functions as a water and CO_2 trap[7]). It will suffice to mention that it combines a very high heat and mass transfer with a very low resistance to flow; moreover, it takes a long time before the channels become blocked with ice and snow. The installation can accordingly be operated continuously for a full working week, and defrosted at the week end. The ice and snow separator mounted on the refrigerating machine and which functions during the starting period, as described above, is of the same type.

The installation consumes a power of 6 kW. Performance data and dimensions are given in *Table I.*

Table I. Particulars of the complete installation PW 7050 for making liquid nitrogen.

Production	4 to 5 litres per hour
Purity	better than 99.5%
Power consumption	6 kW
Specific power	1.2-1.5 kWh per litre
Total production in one working period	500-1000 litres *)
Height	2 metres
Floor area	0.5×2 metres
Total weight	400 kg (approx.)

*) Dependent on the air humidity.

Comparison with other systems

Since the fractionation of air takes place at an extremely low temperature, the most important feature of an installation for producing liquid nitrogen or oxygen from air is, as we have seen, the way in which the low temperature is produced and the requisite flow of heat achieved. The system is of course always designed so that the energy required, other than that for the refrigeration, is kept to a minimum. The systems hitherto employed are on the whole rather complex [8]). One feature they have in common is that the air is compressed before being fed to the fractionating column.

For the liquefaction of gases, particularly in small installations, use is often made of the Joule-Kelvin effect. The gas is first highly compressed and then expanded at low temperature through a porous plug or throttle valve. The gas is thereby cooled and partly condensed. For producing liquid air or nitrogen the compression required is generally in the region of 200 atm, and more air is processed per mol product than in the system described in this article. Another method, used more especially in large installations, is to let a compressed cold gas expand adiabatically (isentropically) by causing it to perform external work on the piston of an expansion chamber or on the rotor of a turbine. Other conditions being equal, the refrigeration with this method is greater than with that employing the Joule-Kelvin effect, less compression being necessary.

The gas refrigerating machine also involves the compression and expansion of a gas. This is done, however, not with the air to be fractionated but with hydrogen or helium in a closed system [9]). Several advantages accrue from not compressing the air feed itself. In the first place, it dispenses with the need for expansion valves. the small orifices of which may freeze up, and secondly there are no moving parts to get ice-bound at low temperature. The absence of moving parts also precludes oil contamination of air and product. Furthermore, since the installation is not required to compress large quantities of air, its construction is relatively light. The fact, then, that the air is not compressed contributes in large measure to the simplicity and reliability of the installation.

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[7]) This will be described in due course in a separate article.

[8]) See note [2]).

[9]) In this respect the installation corresponds to the one earlier described for producing liquid air with the gas refrigerating machine, in which the air to be liquefied is not compressed either.

Summary. In the Philips laboratories an installation has been developed for the economic production of liquid nitrogen from atmospheric air on a moderate scale (e.g. for laboratory purposes). The installation, which consumes 6 kW, delivers 4 to 5 litres of liquid nitrogen per hour with a purity of 99,5%. It consists essentially of an air fractionating column and a gas refrigerating machine (as described earlier in this Review) to produce the necessary low temperature.

The air is pre-cooled in a heat-exchanger by the oxygen expelled as waste product, and further cooled by liquid oxygen contained in a reboiler at the base of the column. It then enters the column as a virtually saturated vapour at a point some way up. The column is an insulated tube 4.5 cm in diameter and 90 cm in height, which is filled with small saddle-shaped pieces of wire-gauze and in which liquid flows from top to bottom and vapour from bottom to top. The liquid in descending becomes increasingly richer in oxygen and contains but little nitrogen when it enters the reboiler at the base. The ascending vapour increasingly richer in nitrogen and leaves the column at the top as almost pure nitrogen. This top product, as it is called, is condensed by the gas refrigerating machine; part of the condensate is extracted as product and part returned to the top of the column as reflux, thus maintaining the downward flow of liquid essential to the functioning of the column. Since the reflux governs the heat transfer from the column to the refrigerating machine, its value is fixed. The thermal properties of nitrogen, which determine this value, are such that the minimum reflux needed for fractionating is amply exceeded. For practical reasons the refrigerating machine is mounted at the side instead of at the top of the column. This makes it necessary to pump the reflux, which is done by means of a "vapour-bubble" pump. Regulation of this pump, and if the exhaust of the waste-product, is fully automatic. The column contains no moving parts that could freeze up, and stoppages are virtually precluded. The heat exchanger, through which the air is sucked in, also functions as a water and CO_2 trap. The installation can operate continuously for a week. The starting period is about $1^1/_2$ hours.

INFLUENCE OF THE PELTIER EFFECT IN RESISTANCE WELDING

537.322.15:621.791.76

During tests on a spot-welding machine for the fabrication of grids for radio valves, the direction of current flow was found to have a marked influence on the strength of the weld. It will be shown below that this at first sight surprising phenomenon can be explained by assuming it to be due to the Peltier effect.

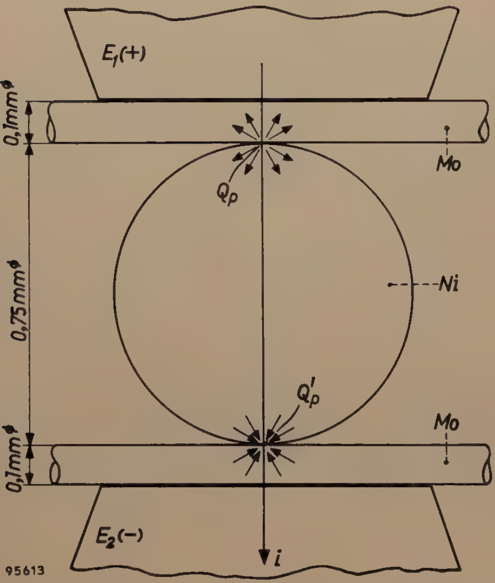

Fig. 1. Sketch of arrangement for spot-welding two molybdenum wires to a nickel wire. If the current i flows from top to bottom in the diagram, an amount of heat Q_P (Peltier heat) is developed at the upper weld and approximately the same amount of heat Q_P' is absorbed at the lower weld. As a result the upper weld has a higher temperature than the lower. E_1 and E_2 are the (copper) electrodes.

The situation is illustrated schematically in *fig. 1.* Two molybdenum wires are simultaneously welded crosswise to a thicker nickel wire, over and under the latter. The welding current is supplied by the discharge of a capacitor through the primary coil of the welding transformer; as a function of time it has roughly the form shown in *fig. 2.* The current is effectively unidirectional; in fig. 1, for example, it flows from top to bottom [1]). Thus, in the upper weld it flows from molybdenum to nickel and in the lower weld from nickel to molybdenum. Now, the Peltier effect is the thermo-electric phenomenon that when current flows through a junction of two dissimilar conductors, heat is developed or absorbed at that junction, depending on the direction of the current. Whether Peltier heat will be developed or absorbed can be deduced from the behaviour of the conductors in question when made to form a thermocouple. From *fig. 3* and its caption we see that in the situation of fig. 1, Peltier heat will be generated at the upper weld and absorbed at the lower. The Peltier heat is added to or subtracted from the ohmic heating, as the case may be. According to this reasoning, then, the upper weld develops the higher temperature. It is in fact found that when the current pulse is just high enough to weld the upper wire firmly, the lower weld is not yet properly consolidated. If the current pulse is raised sufficiently to weld the lower wire firmly, the upper wire usually melts through. If the direction of current flow is reversed the same phenomena occur, but now with the roles of the upper and lower wires interchanged.

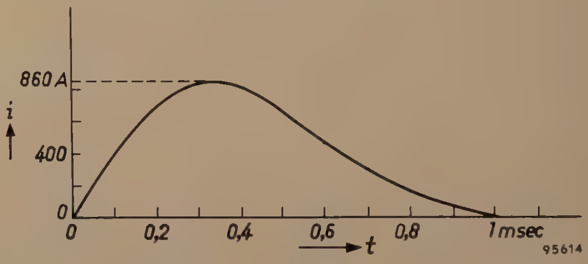

Fig. 2. The welding current-pulse as a function of time.

Although critical adjustment of the current pulse makes it possible to obtain satisfactory welds at both the upper and the lower stations, it takes only a few welds before surface contamination of the electrodes attenuates the pulse enough to prevent a good weld at the lower wire. When the electrodes have been cleaned, a number of good double welds can again be made.

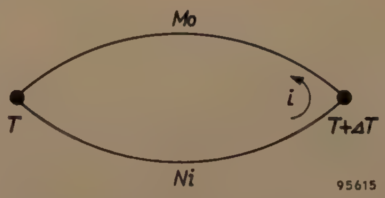

Fig. 3. In a thermocouple formed by Ni and Mo, the current i at the hot junction (temperature $T + \Delta T$) flows from Ni to Mo. The Peltier effect opposes this current flow, i.e. it heats the cold junction (temperature T; heat Q_P is liberated here) and cools the hot junction (where heat Q_P' is absorbed). Thus when a current is driven through an Mo-Ni junction, heating occurs when the current direction is from Mo to Ni.

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[1]) The current pulse of opposite polarity, which follows the first sharp peak, transports just as much electric charge, but it is longer drawn out and reaches nothing like the amplitude of the first peak. For this reason it has little importance in the welding process.

In principle, the Peltier effect occurs whenever two dissimilar materials are jointed by resistance welding. The fact that the effect is so unusually pronounced in the case described is partly attributable to its relatively high value at an Ni-Mo junction, but is mainly due to the fine gauge (0.1 mm) of the molybdenum wire used. With such fine wire a relatively slight rise in the heat developed at the welding zone tips the scales between non-adhesion and a melted-through wire.

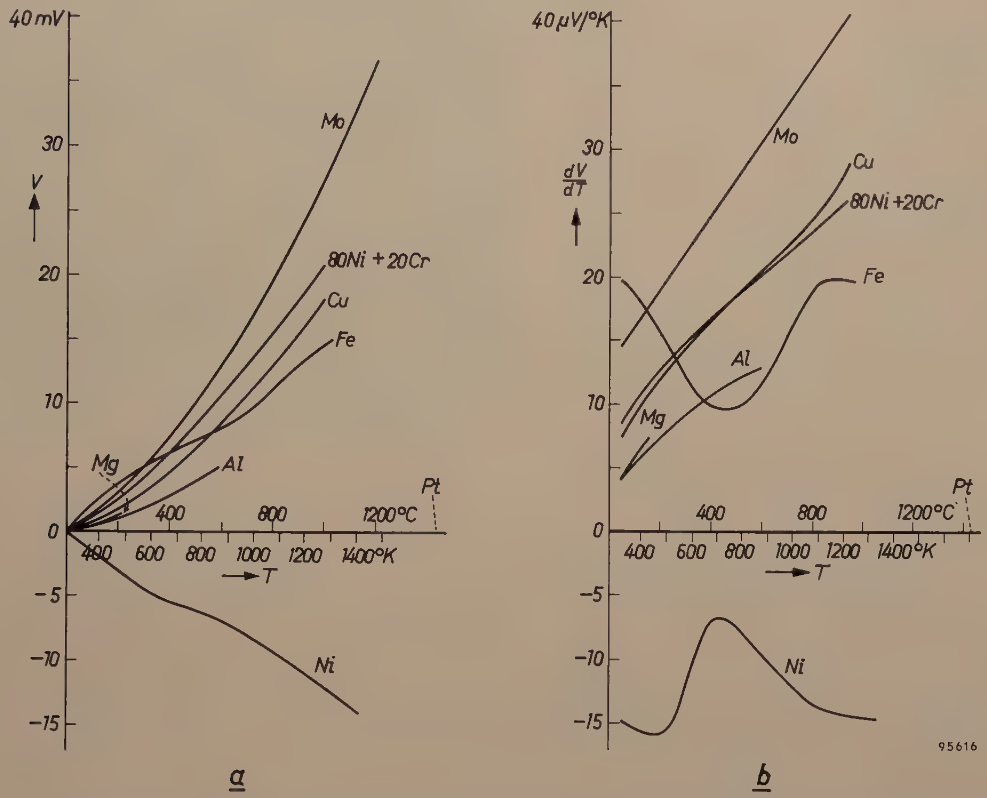

Fig. 4. *a*) Thermo-e.m.f. V of a number of metals, with respect to platinum, as a function of the temperature T of one of the junctions. The other junction is at 273 °K (0 °C). The positive sign means that at the cold junction the thermo-e.m.f. is directed from the metal to the platinum [3].
b) Values of $\mathrm{d}V/\mathrm{d}T$ (the so-called thermo-electric power) as a function of T, derived from the curves in (*a*). As a result of the Peltier effect a junction is heated when a current flows from the metal with the higher value of $\mathrm{d}V/\mathrm{d}T$ to the metal with the lower.

We have already touched on the connection between Peltier heat and the behaviour of a thermocouple made from the contacting metals in question. We shall examine this connection more closely, in order to be in a position to predict whether in a given case the Peltier effect may be expected to influence a weld significantly or not.

Let Q_P be the Peltier heat developed per second, i.e. the Peltier power. This is proportional to the current i through the junction:

$$Q_\mathrm{P} = P i \,. \qquad \qquad (1)$$

The proportionality factor P is the Peltier coefficient, for which one of the Thomson relations is relevant [2]):

$$P = T \frac{\mathrm{d}V}{\mathrm{d}T} \,. \qquad \qquad (2)$$

T is the temperature of the junction in °K. V is the thermo-electromotive force in a thermocouple formed by the two metals concerned, one junction of which is held at a constant temperature while the other has the temperature T. In *fig. 4a* the thermo-e.m.f.'s of several metals with respect to platinum are plotted as a function of temperature [3]). The thermo-e.m.f. for any two metals is found from this graph by measuring the vertical distance between the curves for the metals in question From fig. 4*b*, which sets out the derivatives with respect to T of the curves in fig. 4*a*, the values of $\mathrm{d}V/\mathrm{d}T$ (the so-called thermo-electric power) can be found in the same way for an arbitrary combination of metals. It can be seen from fig. 4*b* that in the case of Fe-Mo, for example, the values of $\mathrm{d}V/\mathrm{d}T$ are appreciably smaller than for Ni-Mo. This implies that if an iron wire were substituted for the nickel wire in fig. 1, it should be easier to obtain good simultaneous welds of the upper and lower wires. Such is indeed found to be the case. Even with Fe-Mo the Peltier effect still makes itself felt, for at a certain setting of the current pulse the upper wire is completely welded and the lower one is still loose. However, a slight increase of current is sufficient to weld both wires firmly. The weld cycle can then be repeated thousands of times without it becoming necessary to clean the electrodes and without there being any tendency for the wires to melt through at one side or break away at the other.

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[2]) See e.g. S. G. Starling, Electricity and magnetism, Longmans, London 1939, 6th edition, pages 210-212. A treatment of Thomson relations, taking account of irreversible processes, will be found in R. C. Tolman and P. C. Fine, On the irreversible production of entropy, Rev. mod. Phys. **20**, 51-77, 1948, in particular pages 70-72.

[3]) The curves are plotted from data given by W. F. Roeser and H. T. Wensel in: Temperature, Report of a symposium held at New York in 1939, Reinhold, New York 1941, pages 1309-1310.

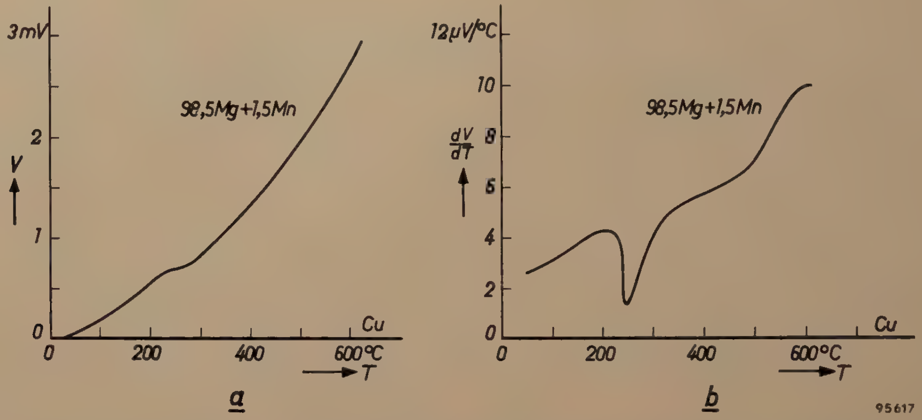

Fig. 5. *a*) Thermo-e.m.f. V of copper with respect to an alloy of Mg with 1.5% Mn plotted against the temperature T; *b*) the derivative of this curve with respect to temperature, again as a function of T.

The Peltier effect also probably explains why, in spot welding, one electrode tip often deteriorates more rapidly than the other (burning and pick-up; the latter being the transfer of electrode copper to the workpiece, or of material from the workpiece to the electrode.) Hess *et al.* [4]) reported in 1947 a detailed investigation of this phenomenon as observed in the spot welding of magnesium alloy sheet — a case of considerable importance in aircraft construction. They found that when welding with current pulses which were mainly unidirectional the positive electrode suffered more than the negative. If the Peltier effect were the cause it should, in the case of Cu-Mg junctions, give rise to additional heating of the positive electrode and to cooling of the negative electrode. To check this, measurements were made of the thermo-e.m.f. in one of the alloys used in the investigation (*fig. 5*). The results showed that the positive electrode does indeed attain the higher temperature (*fig. 6*).

The observations and considerations discussed above prompted a more comprehensive experimental and theoretical investigation of the influence of the Peltier effect in resistance welding. This investigation was undertaken in the Philips laboratory at Aachen [5]). The photograph in *fig. 7*, which

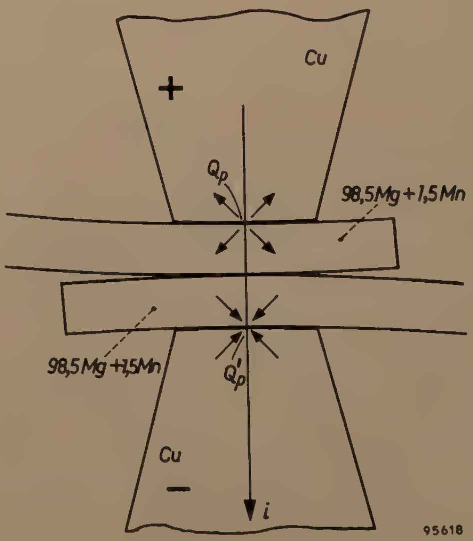

Fig. 6. The Peltier effect may largely explain why in spot-welding one electrode often wears faster than the other. In the welding of Mg sheet, the positive electrode gets hotter, according to fig. 5*b*, and hence deteriorates earlier than the other [4]).

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[4]) W. F. Hess, T. B. Cameron and R. A. Wyant, Observations of electrode tip pickup and tip life in the spot welding of magnesium alloy sheet, Welding Journal **26**, Supplement, pp. 433s-442s and 484s, 1947.

[5]) A report on this investigation, by S. Scholz, will shortly be published elsewhere.

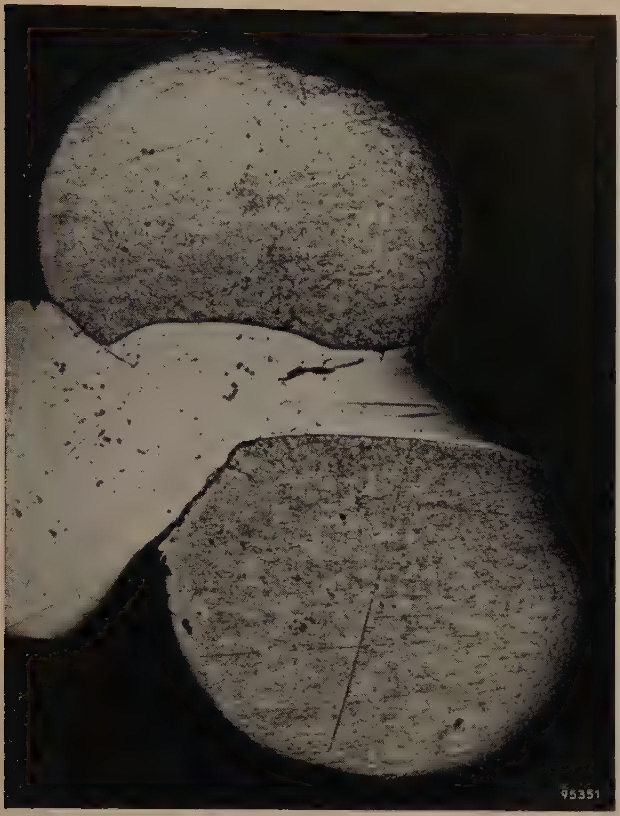

Fig. 7. Cross-section of a weld of two Ni wires on a Ni-Cr wire. Current flows from the top to the bottom wire. In accord with fig. 4*b*, the lower weld has fused farther than the upper. Wire gauge 0.5 mm. This photograph was kindly put at our disposal by S. Scholz of the Philips Laboratory at Aachen.

originates from this source, shows clearly the asymmetry that results from making a double weld such as in fig. 1 when the metal combination shows a large Peltier effect.

Energy involved in the Peltier effect

We shall now make a theoretical estimate of the energy released, or absorbed, in the form of Peltier heat during the welding process. We can then compare this energy with the total energy used for making a weld.

The Peltier heat is given by

$$\int i \times T \frac{\mathrm{d}V}{\mathrm{d}T}\,\mathrm{d}t .$$

The integration is carried out over the duration of the welding process; fig. 2 gives i as a function of time t. In *fig. 8*, $\mathrm{d}V/\mathrm{d}T$ is plotted against T for the combination Ni-Mo (the curve is derived from fig. 4*b*). The same figure shows $T(\mathrm{d}V/\mathrm{d}T)$ as a function of T. We assume further that the temperature T of the weld zone varies as a function of time t in the manner shown in *fig. 9*, it being estimated that the maximum temperature remains about 100 °K below the melting point of Ni (approx. 1700 °K). With the aid of fig. 8 we can now plot the Peltier coefficient $P = T(\mathrm{d}V/\mathrm{d}T)$ as a function of t, and also the Peltier power $Q_P = P \times i$. This is done in fig. 9. The area bounded by the latter curve gives the total Peltier heat, which is found to be 4.2×10^{-2} joule. The capacitor, which contains the welding energy, has a capacitance C of 6.7×10^{-6} farad and is charged to a voltage V_C of 980 V. The energy released upon discharge is $\frac{1}{2}CV_C{}^2 = 3.2$ joule. Estimating that about half of this generates useful heat in the immediate vicinity of both junctions, then 0.8 joule is available per weld. The calculated Peltier heat comes to about 5% of this value. The quantities of heat available for the one weld and for the other thus differ by 10%. This makes it a plausible assumption that the Peltier effect causes a significant discrepancy between the two welds.

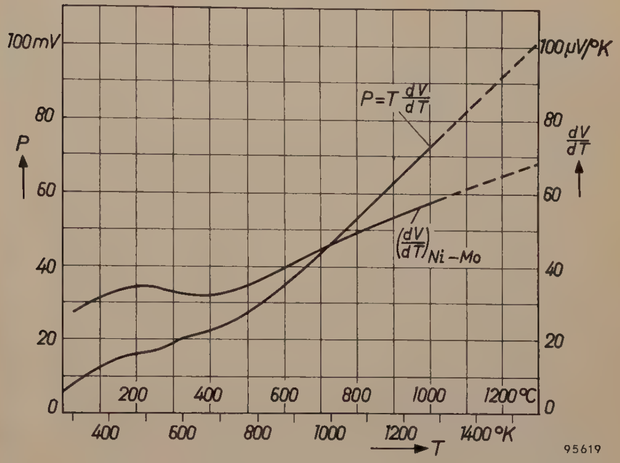

Fig. 8. The thermo-electric power $\mathrm{d}V/\mathrm{d}T$ for the combination Ni-Mo as a function of T (derived from fig. 4*b*), and $T(\mathrm{d}V/\mathrm{d}T)$ as a function of T.

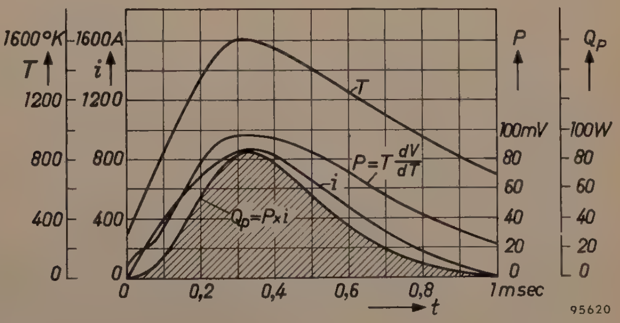

Fig. 9. To calculate the Peltier heat at a junction between Ni and Mo, it is assumed that the temperature T of the welding zone varies as a function of time t in the manner shown. Also plotted as a function of t are the welding current i, the Peltier coefficient $P = T(\mathrm{d}V/\mathrm{d}T)$ and the Peltier power $Q_P = P \times i$.

The Thomson effect

Finally, a word about the Thomson effect. This is the phenomenon that when an electric current i flows through a wire in which a temperature gradient exists, an amount of heat, in addition to the joule heat, will be developed or absorbed, depending on the direction of the current. The Thomson heat developed, or absorbed, per second in an element dx of such a wire is given by

$$\mathrm{d}Q_{\mathrm{Th}} = \sigma\, i \frac{\mathrm{d}T}{\mathrm{d}x}\, \mathrm{d}x . \quad . \; . \; . \; . \quad (3)$$

The proportionality factor σ, which is the Thomson coefficient, is dependent on the material of the wire and on the temperature.

In our case considerable temperature gradients will arise in the molybdenum wires between the weld zones and the welding electrodes. It is therefore reasonable to ask whether perhaps the Thomson effect too will have any significant influence on the weld. The Thomson coefficients of a number of metals (including Mo) have been measured as a function of temperature by Lander [6]); see *fig. 10.* To be able to say anything about the influence of the Thomson effect we assume that at the moment when the weld has reached its maximum temperature (1600 °K) the temperature of the electrode tip is 600 °K. We assume furthermore that the temperature gradient in an Mo wire is linear from weld to electrode. Near the junction, where the temperature is higher than ~1000 °C, the Thomson coefficient in the Mo wires is negative (see fig. 10). A simple calculation shows that in this part of an Mo wire the Thomson power Q_{Th} at the moment under consideration is about 5 W. From fig. 9 we see that the Peltier power is then about 80 W.

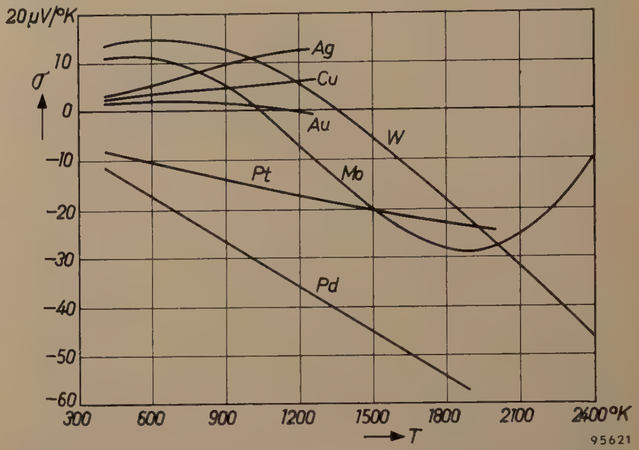

Fig. 10. Thomson coefficients σ for various metals as a function of temperature, after Lander [6]). The sign convention adopted is: a positive value of σ means that heat is developed when the temperature gradient and the electric current are in opposite directions.

The Thomson heating is thus much smaller than the Peltier heating and may be assumed to have no significant influence on the weld. It will have less influence still if thicker wires are welded, for in that case the Thomson heat will not be so concentrated at the junction.

T. C. BALDER.

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[6]) J. J. Lander, Measurements of Thomson coefficients for metals at high temperatures and of Peltier coefficients for solid-liquid interfaces of metals, Phys. Rev. 74, 479-488, 1948.

A FAST METHOD OF READING MAGNETIC-CORE MEMORIES

by H. J. HEIJN and N. C. de TROYE.

621.318.42:621.374.32:681.142

In the operation of a magnetic-core memory, especially as used in electronic computers, the reading of selected cores, the storage of the resultant signals in a buffer register and the restoration to the memory of the extracted information are processes that must be carried out at great speed. Transistors are now proving useful in this respect. After explaining the operation of magnetic-core memories, the article below describes three new circuits. The first employs transistors as intermediate store elements, to provide simple output stages. In the second a transistor is used as a switch to prevent parasitic voltage pules from blocking the output stages; this appreciably shortens the "cycling time", i.e. the time taken to complete the three processes mentioned. The third circuit serves to stabilize the current pulses needed to read the cores and to restore the information. The operation of this circuit is based on the saturation of a ferrite ring.

For some time now, Philips have been supplying components of varying complexity to manufacturers of electronic computers. In this connection research work is in progress on memory systems which employ magnetic materials having a rectangular hysteresis loop [1]). A description wil be given in this article of such a memory system, as used in an experimental computer built in the Research Laboratories at Eindhoven, where it is now in operation.

A "memory" is a device capable of storing numbers, or other data, and of delivering its information when called upon to do so. The following are some typical applications.

1) *Translating machines.* For translating texts from one language into another. The machine "reads" the words and selects from its memory system the equivalents in the other language, while observing the rules of grammar.

2) *Automatic telephone exchanges.* It is required that the *shortest* connection between two subscribers should be established. This takes a certain amount of time, during which the data for connecting the subscribers must be retained.

3) *Automatic lathes.* A memory device is coupled to a lathe while the turner makes a "master" workpiece. All operations are recorded and stored in the memory device, which is subsequently used to control other lathes for producing duplicates.

4) *Electronic computers.* These machines are capable of performing automatically large numbers of calculations. The programmed sequence of operations, the data and the interim results are "written" into a memory or "store". Clearly, such memories are often extremely complex devices.

The binary system

In everyday life numbers are expressed in the decimal system. As the name implies, the base (or radix) of this system is "ten", i.e. it makes use of ten distinct digits from 0 to 9. For a memory device, however, it is more convenient to use the binary number system, which has only the two digits 0 and 1. We shall briefly examine the reasons for this choice.

To explain how a number is represented in a given number system it is useful to distinguish between the *symbol* — meaning the combination of digits — and the *value*, which is the number of units represented by the number. The value follows from the symbol by virtue of the fact that each digital position in the symbol is understood to be a certain power of the base. An example will make this clear. The number represented in the binary system by the symbol 11101 has the numerical value, expressed in the decimal system, of: $1\times2^0 + 0\times2^1 + 1\times2^2 + 1\times2^3 + 1\times2^4 = 29$ (the digits are taken in order from right to left).

A number can be represented in the binary system by a row of similar elements each of which can occur in two distinct states: one of these states is identified with the digit "0" and the other with the digit "1". To do the same in another number system, for example in the 10-based (decimal) or 60-based system, elements are needed that can occur in 10 or 60 distinct states, respectively. If the requirement is to be able to represent numerals up to a given value, fewer elements are needed the larger the base decided on, but the complexity of the elements used increases accordingly. To determine whether the base should be large or small, the product of the number of elements and the number of states per element can be regarded as an indication of the complexity of the total system of representation. It appears that this product is a minimum when the number e (= 2.718 ...) is taken as the base[2]). The nearest integer to this is 3, but 2 is also near, and moreover many simple elements are known which, disregarding transitional states, are essentially on-off (i.e. two-state) devices. For example, a lamp is either on or off, a relay open or closed, a thermionic valve conducting or non-conducting. For these two reasons, the base 2 is virtually the only one used in memory systems.

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[1]) See e.g. H. P. J. Wijn, E. W. Gorter, C. J. Esveldt and P. Geldermans, Conditions for square hysteresis loops in ferrites, Philips tech. Rev. **16**, 49-58, 1954/55.

A digit in a binary number is known as a "bit", which is an abbreviation of "binary digit". By the capacity of a memory is meant the number of bits it is capable of holding.

Types of memory systems

The last ten years have seen a marked increase in the types of memory in use. It would exceed the scope of this article to discuss them all, but it will be as well to mention some of them before dealing at greater length with the magnetic-core type.

Punched cards

Punched cards can be regarded as memory elements in that they store information by virtue of the presence or absence of holes at given positions. The punched card system is one of the few memory systems that existed before the last war. A complete memory consists of a stack of cards and a machine for reading them. Its capacity can be increased at will by adding to the stack. For data to be obtained from a given card, however, the machine must scan the cards in the stack one by one until it finds the card required. The information on a given card is thus not immediately accessible, but is yielded up only after a certain variable "search time" or "access time".

The magnetic drum

The magnetic drum first came into use as a memory during the last war. It consists of a cylinder which is coated with a magnetic material and rotates about its axis at constant speed. Along the surface of the cylinder are arranged numerous magnetic heads which, as in magnetic sound recording, can locally magnetize the surface of the drum. The surface is divided into large numbers of elements, identified by the number of the head under which they pass and by a system of numbered lines traversing the drum parallel to the axis (*fig. 1*). The sense in which a surface element is magnetized is either the same as or opposite to the sense of rotation. The one sense signifies "0" and the other "1". Each surface element thus offers room for 1 bit. The heads serve both for recording (writing) the information and for detecting (reading) it.

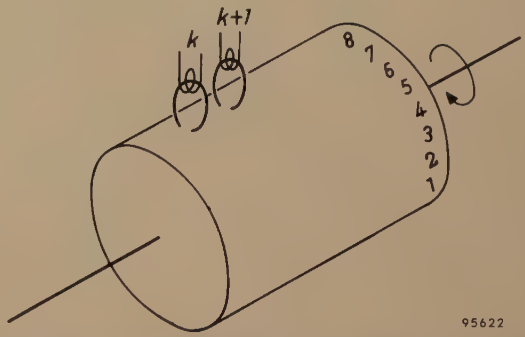

Fig. 1. Schematic representation of a magnetic-drum memory showing the arrangement of the magnetic heads. The surface is divided into elements, each capable of storing one "bit" of information. The position of an element is defined by the number of the magnetic head, *k*, *k* + 1, . . . under which the surface element revolves, and by the number of the parallel line one which the element lies.

The various bits of the same number can be arranged on the same parallel line and simultaneously written or read with all heads. This is called the parallel mode of operation. Another possibility is to arrange the bits of a number so that they pass in succession under one and the same head. This is called the serial mode.

The access time of drum memories amounts on an average to half the time of one revolution.

The information stored in a punched card or magnetic drum memory can be retained indefinitely without the need for special measures to preserve it. This is an advantage over the delay lines and electrostatic memories touched on below. Nor is the information removed by the read-out process, and this distinguishes the punched card and magnetic drum memories favourably from the magnetic core type.

Delay lines

The principle of the delay-line memory is very simple. The information is injected into the line in the form of a pulse train. The pulses travel through the line with a certain velocity, are taken off at the end of the line and returned to the line input via an amplifier which regenerates the original shape and strength of the pulses. Current pulses are used in the case of an electrical delay line. An elastic medium can also be used, however, in which the information is propagated as sound waves (stress pulses). A sonic delay-line often consists of a mercury column. The maximum access time in this case is determined by the length of the column and the propagation velocity of sound in mercury.

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[2]) See, for example, R. K. Richards, Arithmetic operations in digital computers, D. van Nostrand, New York 1955, p. 7.

A drawback attaching to all delay lines is that the regeneration of the pulses calls for complex equipment.

The Williams system

The Williams tube storage system is one of the best known examples of a group of memories in which the information is stored in the form of electric charges (electrostatic memories). In this system the screen of a standard cathode-ray tube is divided into numerous small domains. The electron beam can be directed on to each domain in turn and can write a bit by producing, or not producing, an electric charge.

Like delay lines, electrostatic memories must be provided with a regeneration device, as otherwise the information would leak away.

Magnetic-core memories

In recent years much faster memory systems have been developed which consist of numerous small rings of a ferromagnetic material having a rectangular hysteresis loop [3]). Impetus was given to this development by the advent of ceramic ferromagnetic materials (ferrites [4])), from which very small cores can be made. Ferrites being insulators, there is no difficulty with eddy currents which, when metallic magnetic materials are used, restrict the speed of reading and writing. Examples of the ferrite cores used in the memory circuits dealt with in this article are shown in *fig. 2.*

The induction in a ferromagnetic toroid, which is first driven to saturation and from which the magnetizing field is then removed, can only assume the two values $+B_0$ and $-B_0$ (see *fig. 3*, which shows an idealized loop). If we attach to these two remanent states of magnetization the significance "1" and "0", respectively, we have an element capable of representing one bit, that is, of containing one bit of information. Rectangularity of the hysteresis loop is not necessary in principle, for any shape of hysteresis loop will give rise to two stable states. However, for reasons which will become evident presently, the rectangularity *is* necessary for a practical memory system.

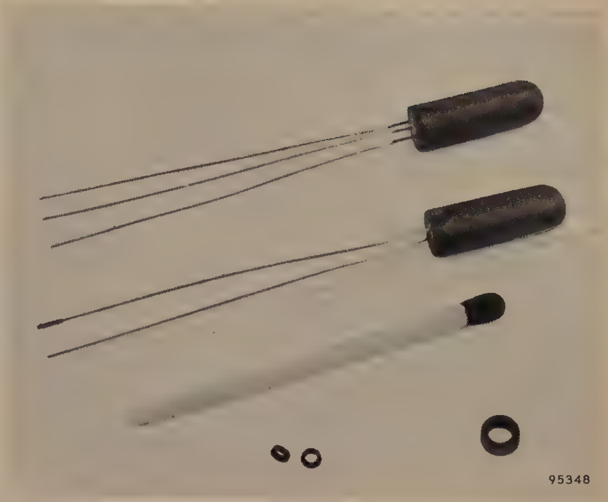

Fig. 2. The basic components of the magnetic-core memory developed at the Philips Laboratories, Eindhoven: a germanium transistor, a germanium diode, rings of ferroxcube 6D3 which serve as memory elements (centre foreground), and a ring of ferroxcube 6E1 as used in a circuit for producing current pulses of stable shape and height.

In order to be able to read the information in a core and if necessary to change it (by reversing the magnetization), the core is threaded with one or more wires through which currents of the requisite magnitude are conducted. The manner in which the wires are threaded through the cores depends on the solution adopted for the selection problem. This requires some explanation.

Since the numbers are often merely a code for information of widely different kinds, they are usually referred to not as numbers but as "words".

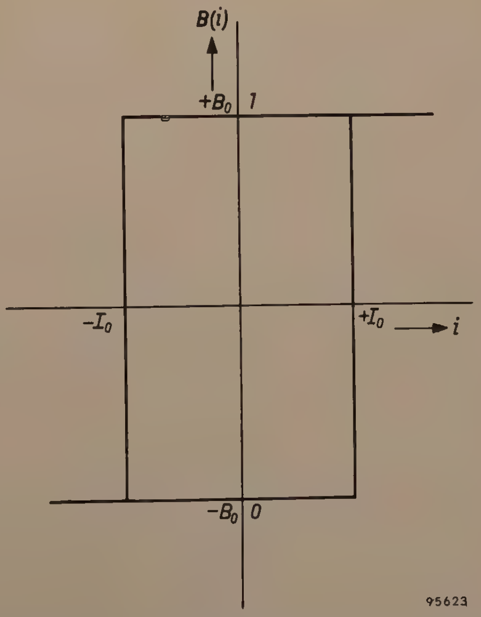

Fig. 3. Idealized rectangular hysteresis loop (induction B as a function of current i) of a magnetic core as used in a memory system. The two states $+B_0$ and $-B_0$ represent respectively the digits "1" and "0".

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[3]) These systems were devised at about the same time, but independently, by J. A. Rajchman (R.C.A. Rev. **13**, 183-201, 1952) and J. W. Forrester (J. appl. Phys. **22**, 44-48, 1951).

[4]) See Philips tech. Rev. **8**, 353, 1946, **13**, 181, 1951/52 and **14**, 245, 1952/53, and also the article mentioned in [1]).

A word, in order to be stored in the memory, is first recorded in a "buffer register". This is a single series of elements which can be in one of two possible states (flip-flops); a pulse arriving at any flip-flop causes it to jump into its other state. The memory is divided into word registers each of which consists of as many cores as the buffer register contains elements. The word in the buffer register must now be transferred to that particular word register of the memory which has been selected for that word. This is one aspect of the selection problem. The other aspect is how to transfer a word from a given word register of the memory into the buffer register. The registers in the memory are also frequently referred to simply as "words"; a memory may be said to be, for example, a memory of 80 words each of 12 bits, which means that it has 80 word registers each of 12 cores, whilst the buffer register likewise consists of 12 elements.

To give a very simple example, we consider a case where each word consists of one bit, so that the buffer register, too, consists of only one flip-flop. A common wire S_x passes through a number of cores $T_1 \dots T_i \dots T_n$, and wires $S_{y1} \dots S_{yi} \dots S_{yn}$, respectively, pass through each core separately (*fig. 4*). Let I_0 be the current needed to change the magnetization of a core from the one remanent state to the other. We assume that the core material has a rectangular hysteresis loop. To read the contents of core T_i we pass through each of the two wires S_x and S_{yi} a current pulse of magnitude $\frac{1}{2}I_0$ in the negative direction as understood in fig. 3. Only core T_i is then subjected to a field strong enough to reverse its magnetization ($\frac{1}{2}I_0 + \frac{1}{2}I_0$); the other cores receive merely $\frac{1}{2}I_0$. If core T_i was set to the "1" state, its magnetization reverses and this induces an e.m.f. in a third wire (not shown in fig. 4) which threads all cores and is connected to the flip-flop of the buffer register. This wire is the "read" or "information" wire (for brevity, denoted I wire). Owing to the rectangular hysteresis loop of the core material, the magnetization of the cores subjected to $\frac{1}{2}I_0$ remains constant. These cores therefore produce no output in the I wire. The flip-flop having previously been set to the "0" state(i.e. the buffer register having been cleared), the e.m.f. induced in the I wire brings the flip-flop into the "1" state, which thus takes over the information from core T_i. If T_i was originally in the "0" state its magnetization is not reversed and therefore no e.m.f. is induced in the I wire. The flip-flop remains in the "0" state and hence again reads the state of T_i.

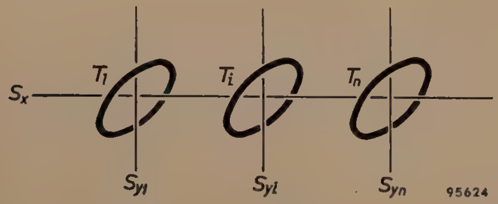

Fig. 4. Magnetic cores with selection wires S_x and S_y. This arrangement constitutes a very simple magnetic-core memory with one bit per word.

Reading the contents of a core evidently amounts to writing an "0" in the core. If the core was in the "1" state it is therefore necessary, if the original information is not to be lost, to restore the "1" after the reading operation. Before discussing a method of thus "regenerating" information, we shall elaborate somewhat on the configuration of fig. 4.

Matrix memories

Fig. 5 shows diagrammatically a collection of cores arranged like the elements of a matrix, hence the name "matrix memory". The matrix in fig. 5 has selection wires in the x and y directions. The cores are situated at the points of intersection. An S_x wire passes through all cores in each row and an S_y wire through all cores in each column. The information wire I is threaded through every core and is again connected with the buffer register flip-flop. Like the single row of cores in fig. 4, the matrix constitutes a memory for words consisting of one bit, and thus the buffer register is again a single flip-flop. Finally, there is another wire threaded through every core — the "inhibit" wire B, whose function will presently be made clear.

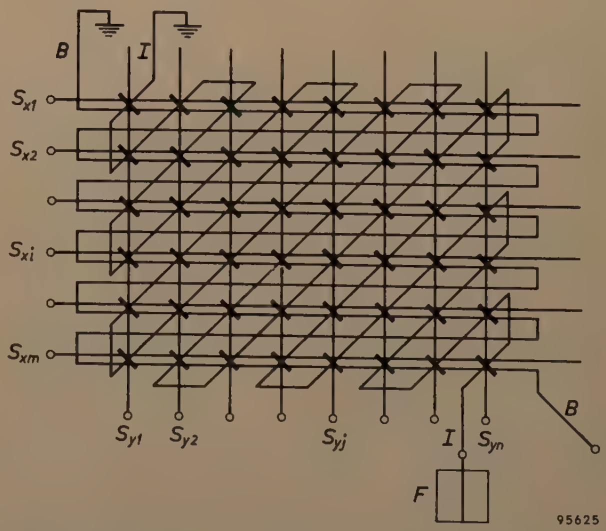

Fig. 5. Extension of the memory in fig. 4 to a matrix arrangement of cores. This register also contains one bit per word. The wires $S_{x1} \dots S_{xm}$ and $S_{y1} \dots S_{yn}$ are the selection wires. I is the information wire; this threads every core and is connected to the flip-flop F which constitutes the buffer register. The inhibit wire B also threads every core.

The information is read in the manner discussed with reference to fig. 4: to transfer the contents of core T_{ij} to the buffer register, negative current pulses of magnitude $\frac{1}{2}I_0$ are conducted simultaneously through the selection wires S_{xi} and S_{yj}. This sets the core to the "0" state. To restore the core to its original state, positive pulses of $\frac{1}{2}I_0$ are arranged to pass simultaneously through the wires S_{xi} and S_{yj} immediately after the read-out. If nothing further happens, the core T_{ij} is thereby brought into the "1" state. If this core was in the "1" state before the read-out, the positive pulses thus achieve their object; if it was in the "0" state, however, it must remain in that state. To ensure that such will be the case, a negative current pulse of magnitude $\frac{1}{2}I_0$ is sent through the inhibit wire B at the same time as the positive pulses pass through S_{xi} and S_{yj}. This negative pulse neutralizes one of the positive pulses and prevents core T_{ij} from changing into the "1" state. Whether or not a pulse *is* sent through the inhibit wire is controlled by the flip-flop in the buffer register which took over the information from core T_{ij}.

Fig. 6 goes a step further. It represents a memory containing words of 5 bits [5]). This memory consists of 5 matrices of the kind discussed above. All wires S_{xi} and S_{yj} with the same index i or j are connected in series; each matrix retains, however, its own information wire I and its own inhibit wire B. When currents $-\frac{1}{2}I_0$ are passed through the wires S_{xi} and S_{yj}, the cores T_{ij} are read (brought into state "0") simultaneously in all five matrices, and the e.m.f.'s which may be induced in the information wires $I_1 \dots I_5$ actuate the five flip-flops of the buffer register which receive the information. To restore the information to the memory the direction of the pulses in the S_{xi} and S_{yj} wires is reversed and at the same time the flip-flops are used to control the five inhibit wires $B_1 \dots B_5$.

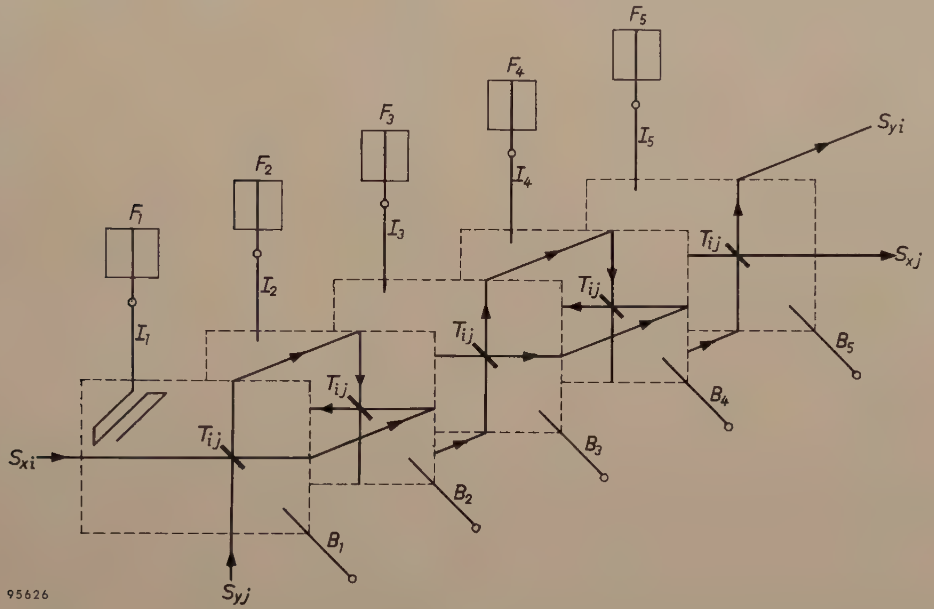

Fig. 6. A magnetic-core memory consisting of 5 matrices as in fig. 5 mounted one behind the other. The selection wires S_x and S_y pass through all five matrices; each matrix, however, has its own information wire I with flip-flop F and its own inhibit wire B, which is driven by this flip-flop.

Disturbing pulses

Let us consider one of the five matrices in fig. 6, i.e. a matrix as in fig. 5. We assume that the core T_{ij} is to be read, and that it is in the "1" state, so that its magnetization reverses in the read-out process. Of all the cores in the matrix, only T_{ij} receives a current pulse $-I_0$; of the other cores, $n-1$ on wire S_{xi} and $m-1$ on wire S_{yj} receive $-\frac{1}{2}I_0$, while no current pulse at all passes through the remainder. Since the hysteresis loop is never perfectly rectangular, small flux changes also occur in the $m+n-2$ cores which simultaneously receive $-\frac{1}{2}I_0$ (*fig. 7*). These flux changes produce in the information wire I, threading as it does every core, spurious signals which can form a resultant disturbing pulse of appreciable magnitude. This pulse is smaller the better the loop-rectangularity of the core material, that is to say the more truly horizontal are the top and bottom of the hysteresis

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[5]) An arrangement as in fig. 6 was first used by J. A. Rajchman; see the first article mentioned in [3]).

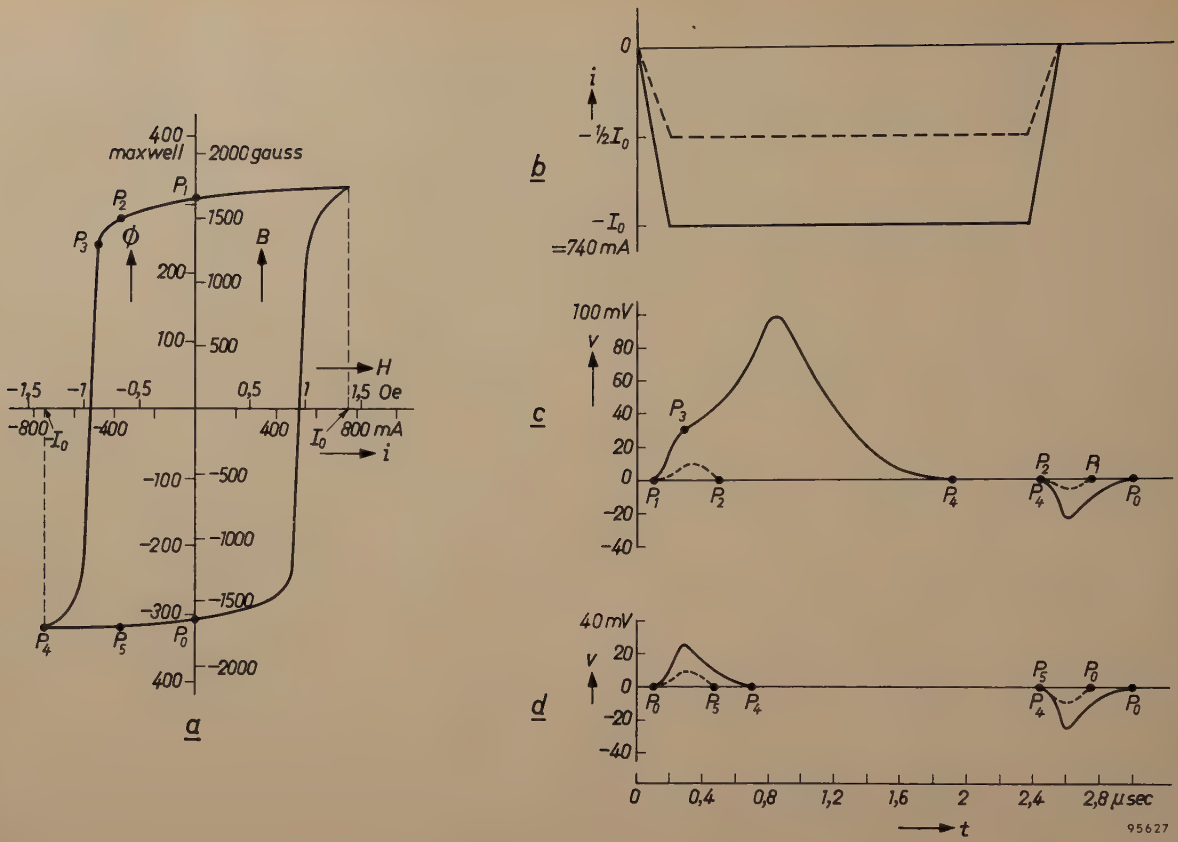

Fig. 7. Hysteresis loop of a core of ferroxcube 6D3 (*a*). If two wires are threaded through the core and a current pulse passes through one of them, a voltage pulse is induced in the other. If the initial state is point P_1 (see *a*), and the current pulse has the form represented by the solid line in (*b*), the point *P* in (*a*) passes from P_1 via P_3 and P_4 to P_0. Voltage pulses are then induced as shown by the solid curves in (*c*). The letters *P* on these curves correspond to those in (*a*). When a current pulse is applied with the wave form shown by the dashed line in (*b*), the operating point in (*a*) moves from P_1 to P_2 and back. The corresponding voltage pulses are shown as dashed curves in (*c*). If the initial state of the core was at P_0, voltage pulses appear as shown in (*d*). Of all these voltage pulses, only the large pulse in (*c*) is the useful one; the others are disturbing pulses.

loop. The magnitude of such a pulse is also markedly influenced by the way in which the *I* wire is threaded through the cores. In fig. 5 this is done in such a way that the *I* wire threads half the cores on an S_x wire in one direction and the other half in the opposite direction. The same applies to the cores on an S_y wire. With this arrangement the disturbing signals largely neutralize each other. A drawback of this threading system is that the cores are distributed in two equally large groups which deliver useful voltage-pulses of opposite polarity. The output amplifier serving the flip-flop must therefore be able to handle pulses of both polarities, which is an added complication. Moreover, the resultant disturbing pulse can, under certain circumstances, still be large enough to give difficulties.

Since disturbing pulses cannot entirely be avoided in this system, means must be found of rendering them harmless in the final output signal. The total signal appearing at the flip-flop has the waveform shown in *fig. 8*. The first peak *p* is due to the unwanted signals; its height is, of course, a function of matrix size, being greater the larger are *m* and *n*. There are two methods of suppressing the effect of this peak. One method is to integrate the total signal.

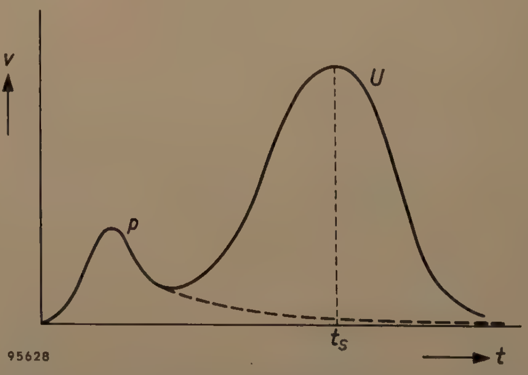

Fig. 8. The total voltage pulse in an *I* wire on reading a core in a memory as in fig. 5 or 6, when this core is in a "1" state. The voltage peak *U* induced by the flux reversal is preceded by a disturbing pulse *p*. The latter is the resultant of the unwanted e.m.f.'s induced by cores situated on the two selection wires which intersect in the selected core. The dashed curve applies when the ring is in a "0" state.

The result of the integration is a signal which is proportional to the area bounded by the curve representing the original signal. The disturbing pulse is of much shorter duration, i.e. much narrower than the pulse caused by a reversal of magnetization, and it therefore contributes little to the integrated signal. The other method makes use of the fact that the disturbing pulse precedes the useful one. If the amplitude of the signal be measured at the moment t_s in fig. 8, a large or small value will be found, depending on whether the selected core was in the state "1" or "0".

But even though the disturbing pulses can be made ineffectual, it is still preferable to avoid them altogether since their suppression involves additional equipment. A memory system has in fact been developed at the Cambridge University Mathematical Laboratory which completely avoids disturbing signals by means of a special method of threading the cores [6]).

The Cambridge system

In the system we have just been considering, the number of two-dimensional matrices equals the number of bits per word, and the number of cores per matrix equals the number of words in the memory. In the Cambridge system all cores are arranged in a single two-dimensional matrix (*fig. 9*). The cores in a column form a word, so that there are as many words as there are columns, and the number of rows is equal to the number of bits per word. We shall now describe how this memory functions.

Reading. A wire which we shall call the A wire (address wire) passes vertically through the cores of each word. To read a word, a negative current-pulse — the reading pulse — with an amplitude equal to or larger than I_0 is sent through the relevant A wire. This ensures that all cores for that word are set to the "0" state. Those cores that were in the "1" state thus undergo a reversal of magnetization and thereby each induce an e.m.f. in the respective information wires, which pass through the cores horizontally. We shall refer to the latter wires as I-R (information-read) wires to distinguish them from the I-W (information-write) wires which are also threaded horizontally through the same cores, and whose function will be discussed presently. The voltage pulses in the I-R wires pass through the output amplifiers Q and actuate the flip-flops F of a buffer register, which, having previously been set to the "0" state, are now changed to the "1" state. The flip-flops that receive no voltage pulse remain unaffected. Plainly, disturbing signals cannot accumulate, for on each I-R wire there is always only one core that receives a current pulse. Another feature that can be of advantage is that in principle there is no limit to the permissible magnitude of the reading pulses in the A wires.

Restoring the information. To return the cores pertaining to the read-out word to their original state, a positive current pulse $\frac{1}{2}I_0$ is sent through the relevant A wire and also through the I-W wires corresponding to the flip-flops which changed to "1" in the reading operation. For this purpose the flip-flops in question control the circuits D which supply the requisite pulses. The coincidence of two positive current pulses $\frac{1}{2}I_0$ causes all cores whose magnetization was reversed by the read-out to return to their former state.

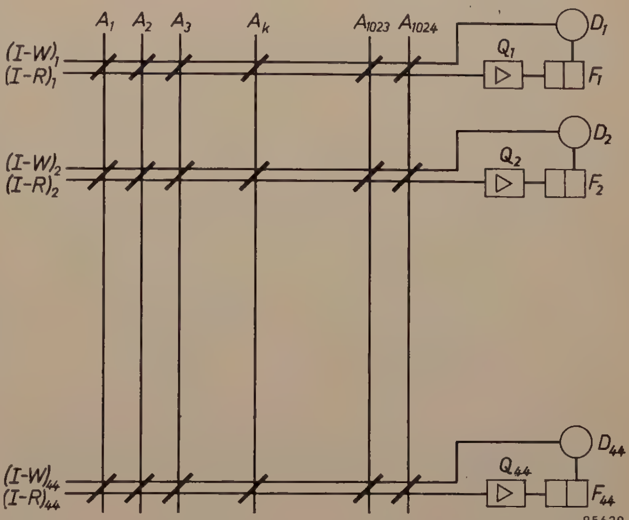

Fig. 9. Simplified diagram of a Cambridge-type memory system. It is assumed that the cores form a matrix of 1024 columns and 44 rows. Each column constitutes one word. Through all the cores of a row are threaded the information wires I-R (for reading) and I-W (for writing). These I wires are connected with the 44 flip-flops F of the buffer register. $Q_1 \ldots Q_{44}$ are the output amplifiers; $D_1 \ldots D_{44}$ are the circuits which supply the current pulses $+\frac{1}{2}I_0$ to the I-W wires for restoring the information after reading. The cores in the columns are threaded by the address wires $A_1 \ldots A_{1024}$, through which current pulses $-I_0$ are passed for reading and half-write pulses $+\frac{1}{2}I_0$ for restoring the information.

In the process as described, the negative reading pulse in an A wire must be equal or greater than I_0, while the sum of the positive half-write pulse in the A wire and that in the I-W wire, required to restore the information, must also be equal to or greater than I_0. The half-write pulses individually, however, and particularly those in the I-W wire, should not exceed $\frac{1}{2}I_0$. Consider, for example, the core (k, 2) in fig. 9 and assume that this is in the "0" state.

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[6]) W. Renwick, A magnetic-core matrix store with direct selection using a magnetic-core switch matrix, Proc. Instn. Electr. Engrs. **104 B**, Suppl. No. 7, 436-444, 1957.

In the $(I\text{-}W)_2$ wire a half-write pulse appears every time a word has been read whose second core was in the "1" state. Whenever this happens, core $(k, 2)$ is disturbed. These repeated pulses shift the operating point of core $(k, 2)$ upwards. If the pulses are not larger than about $\frac{1}{2}I_0$, this process soon stops (*fig. 10*); if they are larger than $\frac{1}{2}I_0$, however, the operating point continues to shift upwards and the information in the core is gradually destroyed [7].

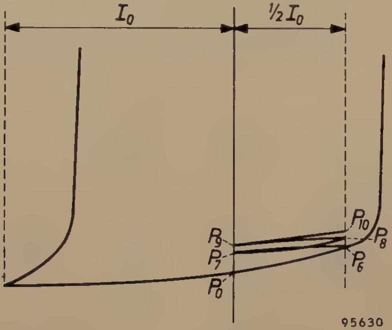

Fig. 10. Displacement of the operating point of a magnetic core as a result of repeated current pulses of magnitude $+\frac{1}{2}I_0$. The operating point lies originally at P_0, corresponding to the "0" state. Under the influence of the first current pulse it moves to P_6, and returns to P_7 upon completion of the pulse. The second pulse brings the operating point via P_8 to P_9. Upon the third and subsequent pulses the operating point continues to move between P_9 and P_{10}. If the magnitude of the current pulses is *greater* than about $\frac{1}{2}I_0$, the operating point continues to shift upwards with successive pulses and the information contained in the core is gradually destroyed.

The half-write pulses in the A wires are less dangerous. In the A_k wire, for example, a half-write pulse appears only after the kth word has been read, and during the reading process all cores of this word (and hence core $(k, 2)$ also) are set to the "0" state. The operating point of core $(k, 2)$ can therefore never shift cumulatively upwards as a result of half-write pulses in the A_k wire. Nevertheless, it is desirable to prevent the half-write pulses in the A wires from causing the critical point P_6 in fig. 10 to be exceeded, and therefore the half-write pulses both in the $I\text{-}W$ and in the A wires should be limited to $\frac{1}{2}I_0$. Since their sum must be at least I_0, they must accordingly be made exactly equal to $\frac{1}{2}I_0$.

We shall now show that the tolerance in these pulses can be widened by applying a *bias current*. Another advantage of a bias current is that it makes it possible for the reading and writing pulses through the A wires to have equal amplitudes.

The bias current

The bias current is a constant negative current I_p which is passed through an additional wire threaded through all the cores, parallel to the A wires. The bias current I_p is usually $-\frac{1}{3}I_0$. The "0" and "1" states then correspond to the points marked as such in *fig. 11*. To read the word at address k (the word through which the A_k wire passes; fig. 9) it is necessary to pass through the A_k wire a negative current pulse $-G$ which is greater than $\frac{2}{3}I_0$ (see fig. 11). For restoring the information, the positive pulse must not be greater than $(\frac{1}{3} + \frac{1}{2})I_0 = \frac{5}{6}I_0$, if the critical point P_6 on the loop is not to be exceeded. If this pulse is also made equal to G, i.e. equal to the read pulse, then $\frac{2}{3}I_0 < G < \frac{5}{6}I_0$, which gives us a certain tolerance for G. The pulse in the $I\text{-}W$ wire should not exceed $\frac{2}{3}I_0$ either. It is preferable to make G larger than the minimum value, since this increases the speed at which the magnetization of a core reverses, resulting in a higher voltage pulse in the $I\text{-}R$ wire. The pulse in the $I\text{-}W$ wire may then be made correspondingly smaller.

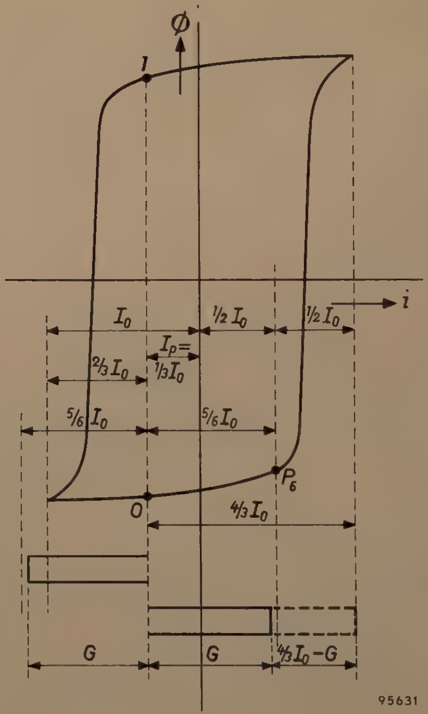

Fig. 11. When the cores are subjected to a constant bias current $I_p = -\frac{1}{3}I_0$, the remanent magnetization states representing "0" and "1" correspond to the operating points marked as such. There is now considerable freedom in the choice of the current-pulse amplitude in the A wires for reading and writing; moreover the pulses can now be made equal in magnitude. For reading (negative pulse) this amplitude G must be greater than $\frac{2}{3}I_0$, but for writing (positive pulse) it must not exceed $\frac{5}{6}I_0$ in order not to pass the point P_6 on the loop (see also fig. 10). The "half"-write pulse through the $I\text{-}W$ wire is represented by a broken line. This is added to the half-write pulse through the A wire.

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[7] See e.g. the article mentioned in [1], pages 57 and 58, and the first article mentioned in [3], pages 192 et seq.

Cycling time

If special measures are not taken, the cycling time is not particularly short for this type of memory. The cycling time is the minimum time that must lapse before a word can again be read. The fact that it is fairly long is due to the large voltage pulse induced in the I-R wire in the writing process (i.e. when restoring the information). The I-W and the I-R wires together can be regarded as two windings which are magnetically coupled by the commonly threaded cores (i.e. as a transformer). The effective permeability of the cores, which is related to the angle made by the top and bottom edges of the hysteresis loop with the i axis, is appreciably greater than 1. For this reason, an e.m.f. is induced in the I-R wire when a current is switched on or off in the I-W wire. In the *latter* case, the e.m.f. has the same polarity as that produced when the magnetization in a core reverses from "1" to "0", but is much larger (e.g. 40 times as large). A normal amplifier is blocked for a certain time by a voltage pulse which is many times larger than that for which it is designed. It is thus necessary to wait until the amplifier has recovered. To prevent blocking one must therefore limit the amplitude of this parasitic pulse. One way of doing this is to connect a diode across the input of the amplifier and to arrange for it to become conductive(and so short-circuit the amplifier) when the pulse amplitude attains a certain value. This, however, is scarcely an improvement, for the effect is to spread the pulse over a period which is longer the more the amplitude is limited. (We do not intend to explain this phenomenon here.) The object of shortening the cycling time is thus not achieved in this way. A method which does achieve this object will be discussed presently.

An improved memory system

The memory used in the experimental computer now in operation in the Philips Laboratories at Eindhoven is a further development of the Cambridge system. Its storage capacity is 1024 words of 44 bits. The inside diameter of the cores employed is 1.3 mm and the outside diameter 1.95 mm. Their height is 0.58 mm (fig. 2). They are made of ferroxcube 6D3; their magnetization reverses at a current $I_0 = 740$ mA.

The memory operates on essentially the same principle as the Cambridge system. We shall first consider 44 cores which together form one word (*fig. 12*). The address wire is now divided into an A-R (address-read) wire and an A-W (address-write) wire. There is also a wire P for the bias current, so that three wires pass vertically through the cores forming a word. The A-R and A-W wires are connected via separate switches to the same current source (not shown in fig. 12). Since the current pulses G must flow in opposite directions for reading and writing, these wires, seen from the current source, are threaded in opposite directions through the cores. The bias current is $-\frac{1}{3}I_0$, hence $-\frac{1}{3}\times 740 \approx$ -250 mA. The value of G must therefore be at least $\frac{2}{3}I_0 \approx 490$ mA, but must remain below $\frac{5}{6}I_0 \approx 615$ mA. In our case G is 600 mA; the voltage pulses on the output amplifier are then about twice as high as when G is minimum.

The I-R and I-W wires are combined to form single I wires, which perform the functions of both reading and writing. This simplifies the threading

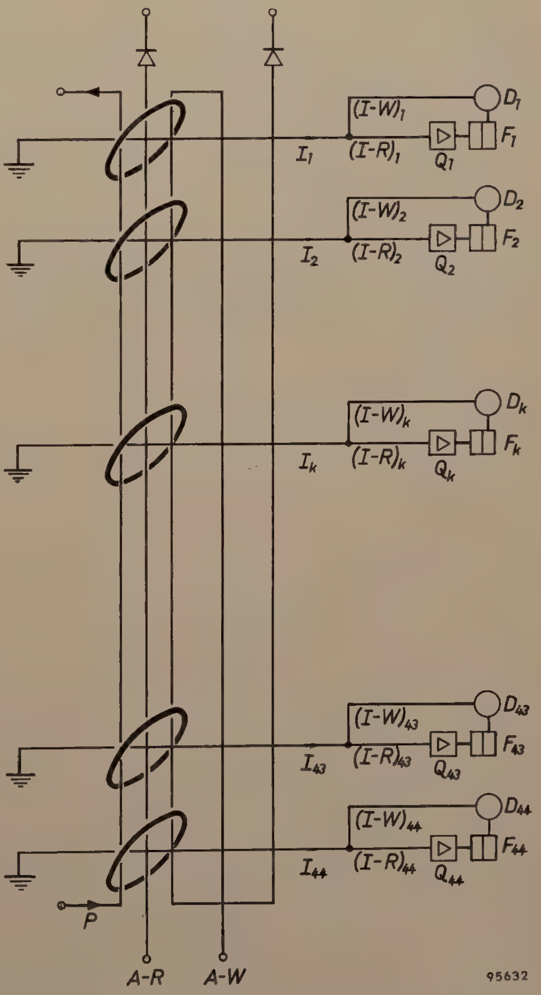

Fig. 12. Arrangement of the cores forming one word in the magnetic-core memory developed at Philips, based on the Cambridge system. The address wire is divided into an A-R wire for reading and an A-W wire for writing. The I-R and I-W wires are combined to form single I wires, which are used both for reading and writing and branch into two only just before the amplifiers Q. These amplifiers operate the flip-flops F of the buffer register. The circuits D supply the current pulses to the I wires for restoring the information; they are controlled by the flip-flops F.

of the matrix. Since G exceeds $\frac{2}{3}I_0$ by a certain amount, the writing current through the I wire (for restoring the information) can be made correspondingly smaller, and need amount to only 380 mA.

The cores of 32 words are arranged in matrix form, corresponding to a Cambridge memory system with 32 words. The complete memory consists of 32 of these matrices, mounted vertically and parallel to each other. Thus the memory constitutes a matrix of $32 \times 32 = 1024$ words. The arrangement, seen from above, is shown diagrammatically in *fig. 13a*. Each core in this figure represents the vertical projection of a word consisting of 44 stacked cores. The details are explained in the caption to fig. 13. A part of the memory is shown in *fig. 14*. The way in which the wires are threaded through the cores can be seen in *fig. 15*.

Reading a word and restoring the information

To read the word at the address (i, j) the switches $(T\text{-}R)_i$ and T_j are momentarily closed. A reading pulse then passes through the $(A\text{-}R)_{ij}$ wire and the selected word appears in the buffer register. The diodes in the $A\text{-}W$ wires ensure that no current flows along forbidden paths via these wires. Next, in order to write the information back into the memory, the switches $(T\text{-}W)_i$ and T_j are momentarily closed. A current pulse then passes through the $(A\text{-}W)_{ij}$ wire in a direction opposite to that of the reading pulse. The diodes in the $A\text{-}R$ wires now prevent the current from following any other path. At the same time the flip-flops in the buffer register, which during the reading process have been set to "1", provide the necessary pulses in the I wires.

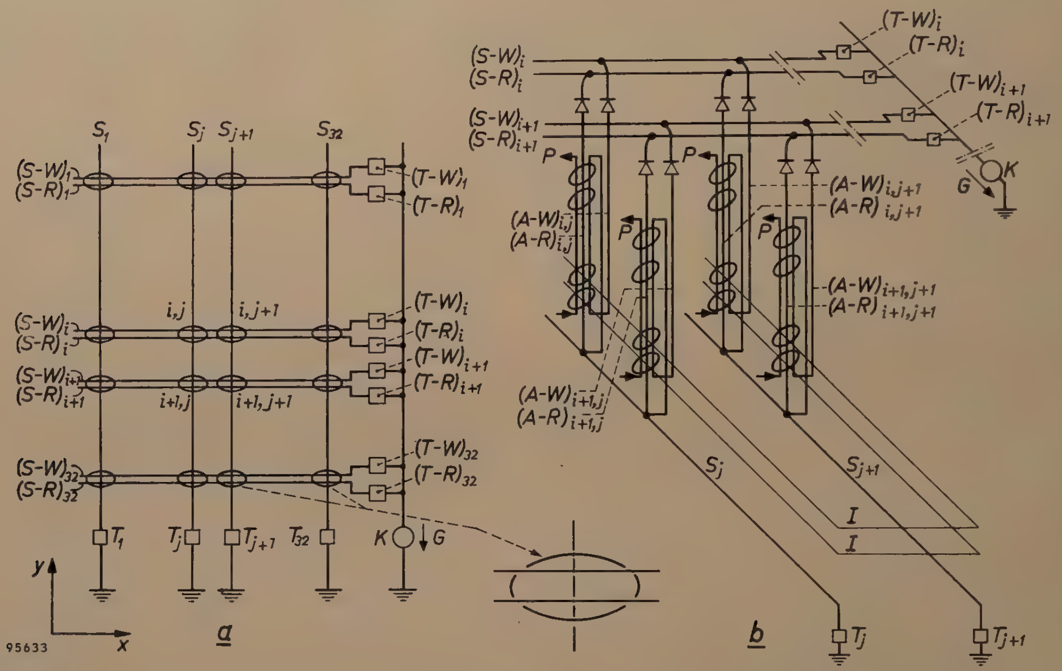

Fig. 13. Principle of the word arrangement in the Philips memory system.
a) Each core drawn represents the vertical projection of 44 cores which together form a word. Through each word (thus downwards in this plan view) are threaded an $A\text{-}R$ wire and an $A\text{-}W$ wire running from the $S\text{-}R$ and $S\text{-}W$ wires threaded in the x-direction at the top of the word, to the S wire threaded in the y-direction at the bottom (see also *b*). All selection wires $S\text{-}R$, $S\text{-}W$ and S possess their own switch, respectively $T\text{-}R$, $T\text{-}W$ and T. When $(T\text{-}R)_i$ and T_j are momentarily closed, the current source K sends a read pulse $-G$ through the word at the address (i, j); when $(T\text{-}W)_i$ and T_j are momentarily closed, the current source sends a write pulse $+G$ through the word. The I wires are not shown in this figure.
b) Perspective drawing of the arrangement of the words at addresses (i, j), $(i+1, j)$, $(i, j+1)$ and $(i+1, j+1)$. In addition to the parts mentioned in (*a*), two of the 44 I wires are shown here, which terminate at the buffer register (not drawn). It can also be seen how the $A\text{-}R$ and the $A\text{-}W$ wires, seen from the current source K, are threaded in opposite directions through the word cores. The diodes in the $A\text{-}R$ and $A\text{-}W$ wires (visible in the photo in fig. 14) ensure that if, for example, switches $(T\text{-}R)_i$ and T_j are closed, the current cannot take any other path than through the $(A\text{-}R)_{ij}$ wire. The wire marked P is the bias wire, which is threaded through every core in the memory.

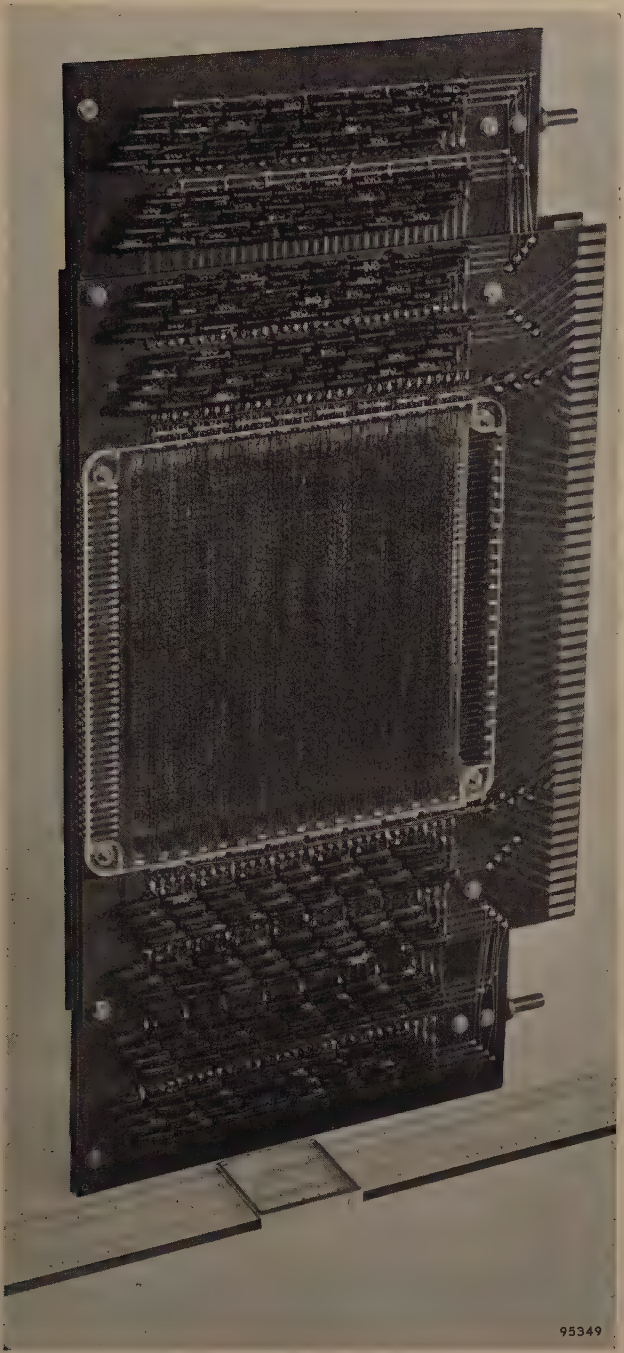

Fig. 14. A part of the Philips memory system. The complete memory consists of four such plug-in units mounted together in a cabinet. The terminal strips seen on the right slide into contact terminals and make the necessary connections with the computer. Use is made of printed wiring [8]. The section shown consists of four matrix groups of 64 columns (the words) each of 44 cores. The complete memory thus has 16 of these matrix groups mounted parallel to each other. This is, however, merely a question of geometric arrangement: electrically the whole memory contains 32 matrices as illustrated in fig. 13. (At the top and bottom can be seen the diodes in the *A-R* and *A-W* wires.)

Output amplifiers

The circuits Q in fig. 12, which, in accordance with usage, we call "amplifiers", scarcely deserve this name. Two *P-N-P* transistors are used, which do not amplify but are used as switches. This application of a transistor depends on the resistance between the emitter and the collector being low when the base current is sufficiently large, and high when the base current is zero.

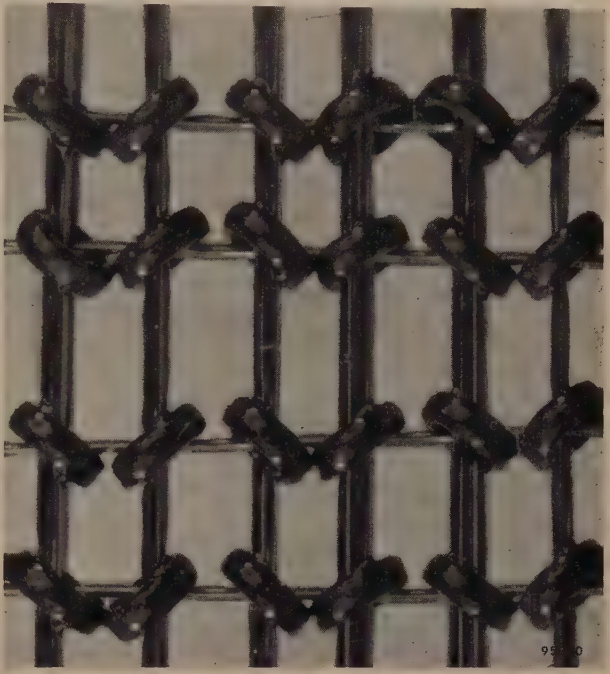

Fig. 15. Detail of the Philips memory, magnified about 7×. It will be seen that four wires are threaded through each core: horizontally the information wire and vertically the two address wires and the bias wire.

The operation of a transistor as a switch may be explained with reference to *fig. 16*. In fig. 16*a* a transistor is shown with a resistor R_E in the emitter lead and a resistor R_C in the collector lead. A current source I_B is included in the base lead and a voltage source (e.m.f. = V_S) in the collector lead. The I_C-V_C characteristics are shown in fig. 16*b* [9], which also shows a load line drawn from point V_S on the V_C axis. The slope of the load line corresponds to the value $R_E + R_C$ (the base current is always small compared with the emitter and collector currents, so that practically the same current I_C flows through R_E and R_C). When $I_B = 0$, the operating point of the transistor is P_1. The collector current is then small and the switch is non-conducting, i.e., open. If, on the other hand, the base current is equal to or greater than I_{B_2}, the operating point is P_2. This results in a high collector current I_{C_2} and the switch is conducting, i.e. closed. The fact that the switch is not an ideal one appears from the small potential difference remaining between emitter and collector. An equivalent mechanical switch is shown in fig. 16*c*.

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[8] See e.g. R. van Beek and W. W. Boelens, Printed wiring in radio sets, Philips tech. Rev. **20**, 113-121, 1958/59, No. 5.

[9] For a discussion of transistor characteristics, see J. P. Beijersbergen, M. Beun and J. te Winkel, The junction transistor as a network element at low frequencies, I. Characteristics and *h* parameters, Philips tech. Rev. **19**, 15-27, 1957/58.

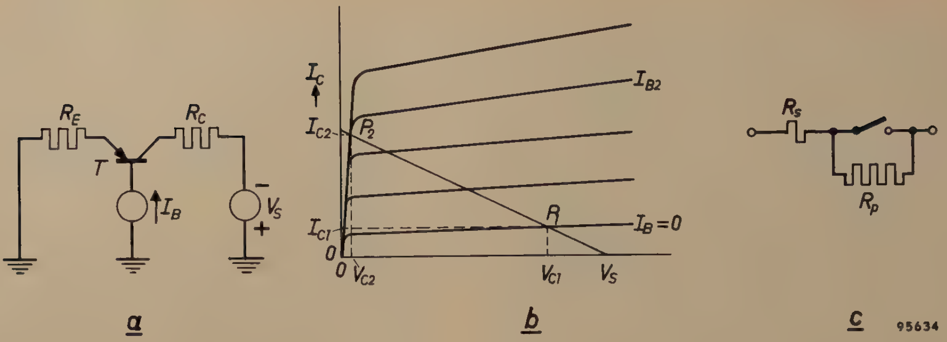

Fig. 16. The transistor as a switch.
a) A transistor T with a resistor R_E in the emitter lead, a resistor R_C and a voltage source V_S in the collector lead and a current source I_B in the base lead.
b) I_C-V_C characteristics with I_B as the running parameter, showing a load line corresponding to the situation in (*a*). When $I_B = 0$, the transistor current is very low (I_{C1}) and the voltage across emitter-collector is high (V_{C1}; switch open). When $I_B > I_{B2}$, the transistor current is high (I_{C2}) and the voltage across it low (V_{C2}; switch closed). The signs of currents and voltages are not specified here.
c) A mechanical switch approximately equivalent to the transistor switch. R_s is a low resistance, R_p a high one.

The circuit diagram of an output amplifier is shown in *fig. 17*. We shall first consider the function of the transistor switch T_2. When, in the reading process, a core undergoes a flux reversal (at which moment the transistor switch T_1 is closed), a voltage pulse appears on the primary of the transformer which will give rise to an open circuit voltage on the secondary of about —6 V. This voltage pulse drives electrons into the base of T_2, thereby producing a base current and making T_2 conducting. Since, however, terminal B is earthed at that moment, the switch is unable to pass current. Now it is a special property of the transistor switch that it remains conducting (closed) as long as there are electrons in the base in excess of the equilibrium concentration. As long as B remains earthed, the excess electrons vanish from the base only by recombination with holes. This takes time, and while it is happening the transistor remains conducting [10]). If during this time a pulse of, say, —10 V is applied to terminal B, terminal C will nevertheless remain at zero potential since it is earthed via T_2 [11]). Care has been taken that the flip-flop connected to C is in the "1" state. (In the present arrangement, clearing of the buffer register involves setting all flip-flops in the "1" state.) The flip-flop therefore remains in the "1" state and represents correctly the state of the read core. If the core is in the "0" state, so that its magnetization is not reversed by the read current, no voltage pulse appears on R_3. Accordingly, no electrons are injected into the base of T_2 and this transistor switch remains non-conducting. When a voltage pulse is now applied to terminal B, terminal C will follow and the flip-flop switches to the "0" state. Here again, then, the state of the flip-flop agrees with the original state of the core.

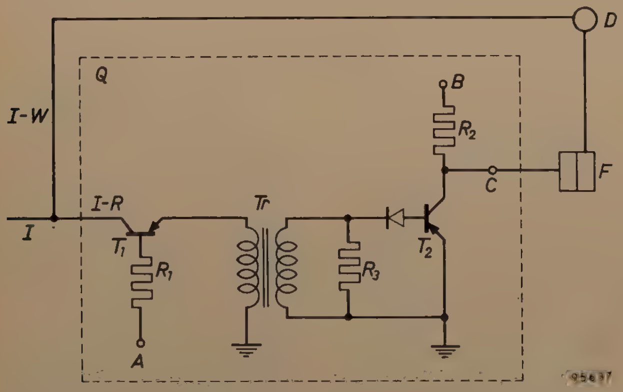

Fig. 17. Circuit diagram of the output amplifiers Q of fig. 12. The transistor T_1 is a switch which makes the connection with the information wire I only at moments when the useful voltage pulses are expected. Parasitic pulses are thus given no opportunity to block the amplifier. Transistor T_2 also acts as a switch, but serves in addition as a temporary storage element, thus making it possible to simplify the circuitry of Q.

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[10]) The existence of this property does not follow from the characteristics in fig. 16*b*, which relate merely to the stationary states. To explain the property it is necessary to consider the phenomena taking place inside the transistor. See e.g. F. H. Stieltjes and L. J. Tummers, Simple theory of the junction transistor, Philips tech. Rev. **17**, 233-246, 1955/56. The property is related to the complex of phenomena comprised under the term "hole storage".

[11]) When a current flows from emitter to collector in a P-N-P transistor, electrons enter the base from the collector and a different number leave the base and go to the emitter (see e.g. Philips tech. Rev. **20**, page 133 et seq.). How long the base remains with excess electrons, i.e. how long the transistor remains conducting after it has been triggered, is therefore no longer dependent solely on the recombination process. Nevertheless, once the transistor *is* conducting it persists in this state for some time.

The function of the diode preceding T_2 is to prevent any positive voltage overshoot over R_3, which might follow the negative pulse, from depriving the base of the injected electrons, in which case switch T_2 would again become non-conducting.

The great advantage of the circuit described is that it provides, with simple means, a certain amount of freedom in choosing the moment at which the pulse is applied to *B*. This is necessary with the computer in which the memory is used, for the flip-flop is not yet free to take over information exactly at the moment it arrives at the output amplifier. This amplifier now retains the information until the flip-flop has completed its previous task. In this way T_2 serves as an intermediate storage element [12]).

The function of transistor switch T_1 is to ensure a short cycling time. We have already seen that, when a current pulse is passed through the *I-W* wire, a high voltage pulse appears in the *I-R* wire which temporarily blocks the amplifier. This was due to the high mutual inductance between the *I-W* and *I-R* wires. These wires are now combined, but the voltage pulse is still produced as a result of the self-inductance of the *I* wire; since this wire threads 1024 cores, its inductance is high. After the *I* wire has passed through the last core, it splits into an *I-R* and an *I-W* wire again. The *I-R* wire is connected with the collector of transistor T_1, whose emitter is earthed via the primary of transformer *Tr*. During the reading of a word, terminal *A* is held at a negative potential with respect to earth; the voltage supply together with the large resistor R_1 forms a current source which supplies a base current high enough to make the transistor switch T_1 conductive. The voltage pulse which is generated by a core that was in state "1" thus appears unhindered on the primary of transformer *Tr*. (While this takes place, the circuit *D* has a high impedance and cannot therefore disturb the pulse in the *I-R* wire.)

When the circuit *D* sends a current pulse through the *I* wire for the purpose of restoring the information, terminal *A* remains open and the base current of T_1 is therefore zero. The transistor switch is now non-conducting, which means that the *I* wire is virtually isolated from the amplifier. We now have a situation which is exactly the opposite of that discussed on page 201, in which the pulse was limited in amplitude, but automatically increased in duration, by the use of a diode. The pulse is now high, but short in duration. However, since the impedance of T_1 (non-conducting) is very large with respect to the impedance of the transformer, the pulse on the transformer is kept small. The pulse is so small there is now no danger of electrons being injected into the base of transistor T_2, which, as mentioned above, would cause this switch to remain conducting for a while, and make it necessary, before reading the next word, to wait until the electrons had recombined with holes. The use of transistor T_1 allows the cycling time to be reduced from 10 μsec, which is the normal value for magnetic-core memories, to 3 μsec. For practical reasons a cycling time of 4.5 μsec has been chosen. *Fig. 18* shows the timing of the various current and voltage pulses.

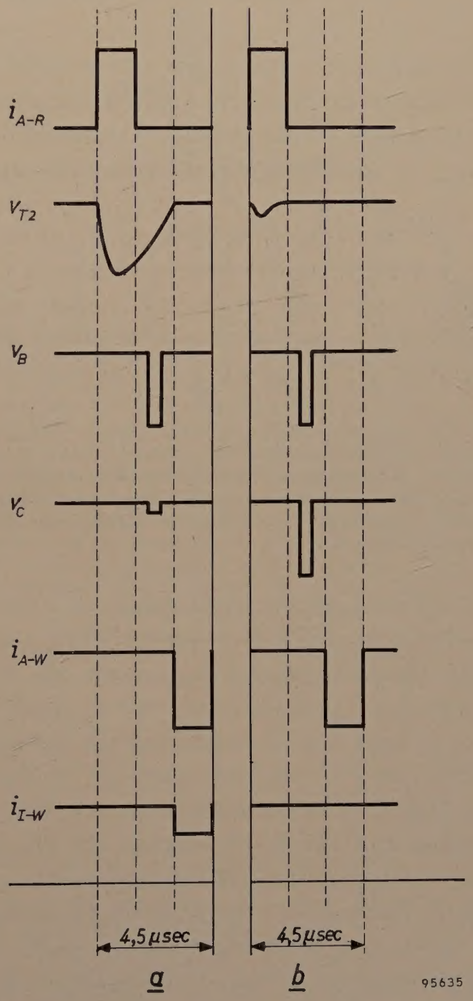

Fig. 18. Timing of the current and voltage pulses over the cycling time (*a*) when reading a core in the "1" state and (*b*) when reading a core in the "0" state. $i_{A\text{-}R}$ read pulse in the *A-R* wire (fig. 12), with amplitude *G* (see fig. 11); v_{T_2} voltage pulse appearing at the base of transistor T_2 (fig. 17); v_B voltage on terminal *B*; v_C voltage on terminal *C*; $i_{A\text{-}W}$ and $i_{I\text{-}W}$ current pulses in the *A-W* and *I* wires for restoring the information. The amplitudes of the latter current pulses are respectively *G* and $\frac{4}{3}I_0 - G$ (see fig. 11).

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[12]) The idea of using a transistor as a temporary storage element is due to H. Rodrigues de Miranda (now with the Philips semiconductor factory at Nijmegen, formerly with the Philips Research Laboratories at Eindhoven).

The selector switches

The selector switches T-R, T-W and T in fig. 13 must be closed during carefully defined intervals in order to form the necessary current pulses. Here, too, transistors are used as switches. Since the currents to be switched are too high for a single transistor of the type used, each switch consists of six transistors connected in parallel (*fig. 19*). A resistor is connected in the emitter lead of each transistor. These resistors ensure that the current is uniformly distributed among the six transistors.

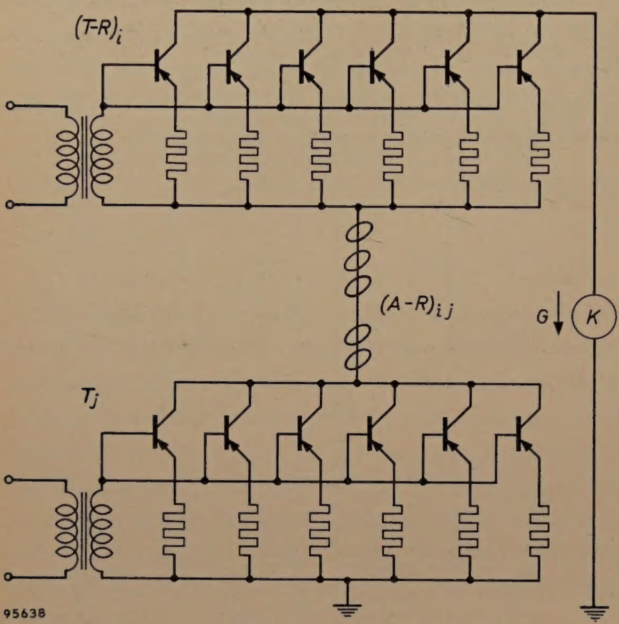

Fig. 19. Two selector switches as in fig. 13, viz. $(T$-$R)_i$ and T_j, which when conducting, allow the current source K to send a read pulse $-G$ through the $(A$-$R)_{ij}$ wire. The switches consist of six transistors connected in parallel. They are made conducting or non-conducting by current pulses through the primaries of their transformers.

The switches are closed by means of a transformer included in each switch circuit. When a current pulse is passed through the primary, the leading edge induces in the secondary a voltage pulse whose polarity is such that electrons are injected into the transistor bases via the base contacts. As discussed on pp. 203, 204, the transistors are thereby made conducting and the switch closes. The transistors remain conducting until the injected electrons have vanished. The trailing edge of the primary current pulse induces a secondary voltage pulse whose polarity is opposite to that of its predecessor. This pulse withdraws what remains of the injected electrons from the base, so making the switch non-conducting. A switch is thus open during time intervals which exactly coincide with the drive pulses through the primary of its transformer. The incidence and duration of the small drive pulses can be controlled with sufficient accuracy by conventional means. The transistors used are of the high-frequency type; they have very thin base, and a small injection of electrons is sufficient to make them conducting. Only small pulses are thus needed for driving the selector switches.

The current source

As earlier explained (page 202), in order to read the the word from the address (i, j), the switches $(T$-$R)_i$ and T_j are momentarily closed. The current source K in fig. 19 (see also fig. 13*a* and *b*) is then connected to earth via the $(A$-$R)_{ij}$ wire. This current source must meet certain stringent requirements. Depending on the number of word cores which undergo a flux reversal, an inverse voltage of varying magnitude is induced, but this must not be allowed to have any appreciable effect on the magnitude or shape of the current pulse. An obvious solution is to make up the current source from a voltage source of high e.m.f. in series with an adequately high resistance. In the intervals when no current is being drawn — i.e. when all selector switches are open — the full e.m.f. would then be across the emitter and collector terminals of the transistors. This e.m.f. would be substantially higher than the maximum voltage of 15 V permissible across the transistors. For our purposes, then, another solution must be found.

The current source employed consists of a voltage source connected in series not with an ordinary resistance but with the secondary of a transformer (*fig. 20*). The transformer core consists of a ring of ferroxcube 6E1 ("switch core"). This material also has a rectangular hysteresis loop but its "flux-reversal time" or "switching time" is longer than that of the material 6D3 used for the memory cores [13]).

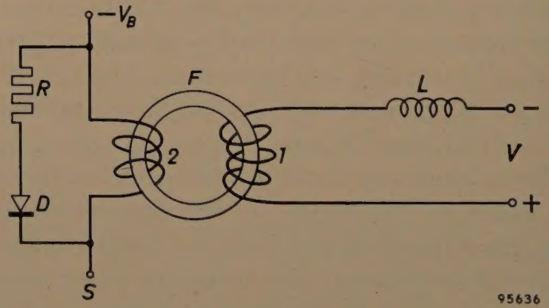

Fig. 20. The current source K of figs. 19 and 13. Through the primary winding *1* of the ferroxcube core F a constant current is passed, supplied by the current source formed by the voltage source V in series with a choke L. The secondary winding *2* is connected at one end to the voltage source $-V_B$ and at the other end S to the selector switches T-R and T-W. The resistor R and the diode D prevent the build-up of a high voltage when the secondary is interrupted.

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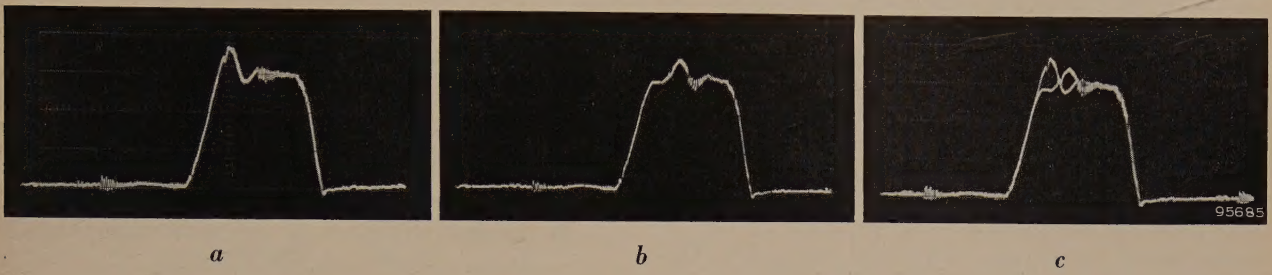
[13]) See H. van der Heide, H. G. Bruijning and H. P. J. Wijn, Switching time of ferrites with rectangular hysteresis loop, Philips tech. Rev. **18**, 336-346, 1956/57.

A switch core of this kind is included in the photograph of fig. 2. Through the primary winding (*1*, fig. 20) a constant current is passed which is supplied by a source of conventional design — i.e. consisting of a voltage source in series with a choke — and which is powerful enough to keep the current constant notwithstanding the fluctuations on the secondary winding of the transformer. The secondary winding (*2*) is therefore effectively a choke. The primary current is so high as to saturate the ferroxcube core, consequently the self-inductance of the choke is low. If two selector switches are closed (see fig. 19) a secondary current flows which increases rapidly in magnitude owing to the low inductance of the choke. However, the sense of the current through the secondary is such that it attenuates the field produced by the primary current. If the secondary current reaches a value such that the core is no longer saturated, the self-inductance of the choke rapidly increases, and from that moment the secondary current rises only very slowly. After some time, however, this current would nevertheless attain a value capable of saturating the ferroxcube core, but now in the opposite direction. In that case the secondary current would again increase rapidly. The circuit must therefore be designed so that the selector switches open again before this renewed saturation can take place [14]).

When the secondary current is interrupted, the core rapidly returns to its original state of saturation. The flux change to which this gives rise induces in the secondary winding a high voltage pulse of the same polarity as the battery voltage $-V_B$. Measures are needed to prevent this voltage from appearing over the transistors. In the circuit described, this voltage is short-circuited by means of a diode, in series with a resistor, connected in parallel with the secondary winding.



a *b* *c*

Fig. 21. Oscillograms of a current pulse as supplied by the current source in fig. 20, (*a*) when none of the cores undergoes flux reversal, and (*b*) when the magnetization of all cores reverses. The fact that both current pulses are almost identical can be seen by their close coincidence in (*c*), where they are recorded as a single oscillogram.

The efficiency of the circuit is demonstrated by the oscillograms in *fig. 21*, which show the current pulses when none and when all 44 cores of a word undergo a reversal of magnetization.

Summary. The article first reviews various types of memory systems as used in computers and telephone exchanges, etc., namely punched cards, magnetic drums, delay lines, electrostatic memories and magnetic-core memories. The latter are then dealt with at greater length. Their operation depends on the use of large numbers of small rings (cores) of a ferroxcube material having a rectangular hysteresis loop. Wires threaded through the cores conduct the current and voltage pulses required for recording and reading the information. There are various methods of threading the wires. Considerations relating to disturbing pulses, which arise as a result of the imperfect rectangularity of the hysteresis loops, have led to a special system of threading known as the Cambridge system. This system has been further developed at the Philips Research Laboratories in Eindhoven. A version is described which employs cores of ferroxcube 6D3. This memory contains 1024 words of 44 bits; its special feature is its low cycling time, which need be no more than 3 μsec, i.e. about 1/3 of the value hitherto considered as normal in such memories. This is achieved by preventing parasitic pulses from blocking the output amplifiers. When a parasitic pulse arrives, the amplifier inputs are isolated by means of a transistor used as a switch. Each amplifier contains a second transistor, also used as a switch, its use being based on the circumstance that a transistor is capable of storing for a few μsec the information read from the memory. The flip-flops of the buffer register are thus given an opportunity to complete their previous task before taking over the information from the output amplifiers. A further feature is the way in which the current pulses for reading and for restoring the information are stabilized in shape and magnitude, independent of the number of cores whose magnetization is reversed at the same time. For this purpose advantage is taken of the circumstance that the inductance of a choke is greatly diminished when the choke core is saturated.

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[14]) The possibility of using a ferrite core in the manner described was suggested by T. Tulp of the Philips Research Laboratories at Eindhoven.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS BY THE STAFF OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

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2575: G. W. van Oosterhout and C. J. M. Rooijmans: A new superstructure in gamma-ferric oxide (Nature **181**, 44, 4 Jan. 1958).

The structure of γ-Fe_2O_3 has hitherto been considered to be the spinel structure in which Fe^{3+} vacancies — possibly in combination with H^+ ions — are randomly distributed over octahedral sites. Accurate X-ray diffraction has shown that in fact the vacancies are ordered. The unit cell consists of three spinel blocks one above the other ($Fe_{64}O_{96}$) in which the 8 vacancies ($Fe_3O_4 = Fe_{72}O_{96}$) are distributed according to a four-fold screw axis.

2576: J. Verweel: Fysische eigenschappen van ferromagnetische oxydes (Ingenieur **70**, O 7-O 11, 1958, No. 2). (Physical properties of ferromagnetic oxides; in Dutch.)

The physical properties of magnetic materials are briefly described. A review is given of some properties of magnetic oxides. The ferromagnetic resonance phenomenon is explained and shown from measurements of the complex permeability versus frequency of some NiZn ferrites.

2577: L. Seekles, P. Reitsma, T. J. de Man and J. H. G. Wilson: Resultaten van de tijdige intraveneuze toediening van hoge doseringen kristallijn vitamine D_3 in gesolubiliseerde vorm aan rundvee ter voorkoming van melkziekte (T. Diergeneesk. **83**, 125-136, 1958, No. 4). (Results of the timely intravenous injection of large doses of crystalline vitamin D_3 in solubilized form in cattle as a preventative against milk fever; in Dutch.)

Following a survey of the relevant literature, three experiments are described which were carried out with the purpose of investigating the possibility of preventing milk fever in cows by the administration of a massive dose of vitamin D_3. The investigations, in which the University of Utrecht, the Animal Health Service in the Noord-Holland Province, veterinary practitioners in the same province and N.V. Philips-Roxane closely collaborated, were carried out under practical conditions for three consecutive years, during the early months of 1955, 1956 and 1957. All cows used in these investigations, a total of about 150, had suffered from milk fever at least once and were chosen from farms with a history of milk-fever occurrences. The results show that milk fever in cows can be prevented significantly by the timely intravenous injection of 10 million I.U. of crystalline vitamin D_3 in a solubilized form (10 cc "Duphafral" D_3-1000, N.V. Philips-Roxane) administered during a period of from 2 to 8 days prior to parturition.

2578: J. de Boer: Microscopisch onderzoek van de domeinstructuur in polykristallijn bariumtitanaat (Chem. Weekbl. **54**, 137-141, 1958, No. 11). (Microscopic investigation of the domain structure in polycrystalline barium titanate; in Dutch.)

Polished and etched specimens of polycrystalline barium titanate are microscopically examined. No big changes in the domain structure are observed after polarization perpendicular to the surface. From observations on single crystals the conclusion was formed that the domain structure is strongly influenced by mechanical stresses. In Mn_3O_4, which is neither ferromagnetic nor ferroelectric, a twinning pattern analogous to a domain structure can be observed which is due to mechanical stresses alone. It is concluded that in polycrystalline barium titanate the polarization of the domains can be reversed, but 90° rotation is strongly hindered. The maximum attainable polarization is therefore much lower than that of single crystals.

2579: H. G. Bruijning: Some components used in the nanosecond field (Nucl. Instr. **2**, 81-87, 1958, No. 2).

General discussion of some of the properties required of valves, transistors, crystal diodes and transformers for applications involving nanosecond pulses.

2580: A. van der Ziel and A. G. T. Becking: Theory of junction diode and junction transistor noise (Proc. Inst. Electr. Engrs. **46**, 589-594, 1958, No. 3).

A. van der Ziel has given formulae for shot noise in junction diodes and junction transistors for transistors in which 1) all current is carried by one type of carrier, 2) the carrier flow is one-dimensional, 3) the recombination is by volume recombination. These equations are here proved with the help of a corpuscular approach without any significant restrictions except that the individual holes can be treated as independent. The emitter and collector currents are then split into various parts for which the noise spectrum can be obtained by relatively simple reasoning.